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SOIL SCIENCE

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A COMPARISON BETWEEN THE PIPETTE METHOD AND THE HYDROMETER METHOD FOR MAKING MECHANICAL ANALYSES OF SOIL

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The hydrometer method has been presented (1, 2, 3, 4) as a very rapid, simple, and reasonably accurate method for making mechanical analyses of soil. Since it was first proposed about 7 years ago it has undergone considerable improvement, and in the present form more than 800 persons all over the world both in educational institutions and in industries are using it. Its widespread adoption clearly indicates that there has been a great need for such a method.

Since the pipette method has been adopted by the International Society of Soil Science as the standard method for making mechanical analyses of soil it was decided to compare the hydrometer method with it, and to ascertain to what extent the results obtained by the two methods agree.[1]

The writer first obtained from the United States Bureau of Chemistry and Soils samples of 15 different types of soils together with their mechanical analyses as obtained by the pipette method. These soils were then analyzed by the hydrometer method, and it was found that what the pipette method determined as clay (0.005 mm.), the hydrometer method would determine at the end of 1 hour and what the pipette method determined as fine clay, or colloids (0.002 mm.), the hydrometer method would determine at the end of 2 hours. The data obtained on these soils by the hydrometer method show that the hydrometer method can give results on the clay content of soils that are identical with those obtained by the pipette method.

After this preliminary comparison was made it was decided to test the hydrometer method further by using unknown soils. Accordingly, the United States Bureau of Chemistry and Soils sent the writer 19 different soils without their mechanical analyses. These soils were selected to represent many unusual types and also some types that had unusual particle distribution. It was agreed that the writer was to analyze these soils by the hydrometer method and the United States Bureau of Chemistry and Soils was to analyze the same soils both by the hydrometer method and by the pipette method. After the writer obtained his results, he submitted them to the United States Bureau of Chemistry and Soils without knowing the results it had obtained on the

[1] In this comparative study of the two methods, the writer is indebted to the United States Bureau of Chemistry and Soils for its coöperation and help.

soils by either the pipette or hydrometer method. The results obtained are shown in table 1.

An examination, first, of the results obtained on clay (0.005 mm.) shows that with very few exceptions the two methods agree very well in the different soils. The principal exceptions are soils 12, 17, and 18, but there seem to be definite explanations for these exceptions. Soil 12, for instance, is a soft bauxite with soft concretions which can be easily crushed between the fingers. A mechanical analysis of this soil has not much significance. Soils 17 and 18 contain a

TABLE 1

Comparison between hydrometer and pipette methods

SOILS	CLAY (0.005–000 MM.)			FINE CLAY (0.002–000 MM.)		
	Hydrometer by Bouyoucos	Pipette by U. S. Bur. of Soils	Hydrometer by U. S. Bur. of Soils	Hydrometer by Bouyoucos	Pipette by U. S. Bur. of Soils	Hydrometer by U. S. Bur. of Soils
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
1. Marshall silt loam 0–14″	30.7	31.2	28.9	27.2	27.8	27.3
2. Marshall silt loam 14–18″	35.6	36.0	35.4	31.4	32.1	31.4
3. Miami silty clay loam 0–10″	37.0	34.0	35.4	31.3	22.4	31.3
4. Miami silty clay loam 10–24″	69.5	74.8	73.8	63.8	62.6	68.8
5. Soil from Fallon, Nevada	42.1	37.9	39.6	37.2	28.9	35.2
6. Davidson loam 0–9″	35.9	34.0	36.1	31.0	23.5	30.1
7. Davidson loam 9–36″	62.1	59.1	59.3	58.4	49.4	56.4
8. Superior fine sandy loam 12–30″	5.6	6.6	10.0	5.2	5.9	8.1
9. Superior fine sandy loam 30–40″	2.8	3.0	7.5	2.7	2.5	5.5
10. Amarillo silty clay loam 10–20″	47.8	46.5	44.4	43.6	42.2	41.3
11. Amarillo silty clay loam 70–75″	55.00	55.3	54.1	50.2	37.2	48.7
12. Soft bauxite 156–214″	29.8	17.8	x	24.0	11.8	x
13. Houston black clay 0–3″	56.1	60.8	54.5	49.0	43.8	46.7
14. Houston black clay 14–20″	61.3	64.8	59.4	53.8	45.5	50.1
15. Houston black clay 36–50″	54.9	56.6	53.1	48.6	34.6	44.7
16. Cecil clay loam 5–36″	34.7	29.9	33.1	31.6	22.9	30.1
17. Cecil clay loam 36–72″	16.7	9.5	18.2	14.0	7.6	14.2
18. Cecil clay loam 96–112″	11.8	5.2	11.9	9.8	2.7	11.1
19. Sharkey clay soil	68.4	70.5	68.5	63.0	58.5	58.9

considerable amount of mica in the form of flakes, and it is possible that the dispersing machine used in the hydrometer method either broke down the mica into fine material or it dispersed the whole soil more completely than did the shaking machine used in the pipette method.

It is to be noted in soils 8 and 9, which are fine sands, that the writer's hydrometer results agree with those of the pipette method whereas the Bureau's hydrometer results do not agree very closely either with the writer's or with those of the pipette. The reason for this disagreement is that the writer dispersed these sands for 5 minutes only and made a correction for the hydrometer as the directions call for, whereas the United States Bureau of Chemistry and

Soils dispersed these soils for 10 minutes, the same as for clay, and did not make the correction. It has been found advisable to disperse the sands only about 5 minutes because the dispersing machine is so powerful that it tends to break down some of the sand particles, especially those that are not very refractory.

Outside of these three or four special cases the results of the pipette and hydrometer methods agree very well in determining the clay. This agreement is remarkable when it is considered that the hydrometer method completes the determinations in 1 hour as against several days by the pipette method. Where there is any marked disagreement it appears to be due entirely to the question of dispersion and not to the hydrometer instrument itself.

An examination, next, of the results on fine clay (0.002 mm.) shows that the two methods do not agree so closely as they do in the case of the coarser clay. It is also observed that the results obtained by the hydrometer tend to be somewhat higher than those obtained with the pipette. Several explanations may be offered to account for some of these variations. One is that the dispersing machine used in the hydrometer method dispersed the soils more completely than did the shaking machine used in the pipette method. Second, the dispersing reagents employed to stabilize the soil suspensions tend to lose their stabilizing effects in some soils on long standing, and, since in the pipette method the soil suspensions are allowed to stand for 8 hours before the reading is taken as against 2 hours in the hydrometer, it is probable that the settling of the particles in some of the soils was more rapid in the pipette method than in the hydrometer method. Third, in the pipette method only sodium oxalate was used as a dispersing reagent, whereas in the hydrometer method a combination of sodium oxalate and sodium hydroxide was employed, and, as will be shown subsequently, different dispersing reagents affect the dispersion and stabilization of the various soils differently. Fourth, the soils which show variations in the clay content probably contain a very wide particle distribution, and the pipette and hydrometer methods do not measure the same soil particles in such cases. That is to say, when a soil has a very wide distribution of particles, the hydrometer method tends to measure or throw in the class of fine clay some soil material that is coarser than the upper limits of the fine clay. Which one of these explanations is the correct one cannot be said at present. It would seem that they might all contribute in causing the variations in the results but in different degrees, depending upon the soil.

In connection with the disagreement that is exhibited by the results from pipette and hydrometer methods in some soils in table 1, it will now be of much interest and significance to study the disagreement that is revealed within results by the pipette method itself when used by different investigators to analyze the same soils by the same procedure.

This information is contained in the report (6) of the Second International Congress of Soil Science, held in Russia in 1930. The Soil Congress had a large number of laboratories all over the world do cooperative investigation on

the pipette method. Samples of six different soils were sent to these various laboratories to be analyzed by the pipette method according to the same directions to determine how the results from the different laboratories would compare. The results as reported are shown in table 2.

Table 2 shows that the agreement of the various laboratories on the determination of the clay content of the same soils is distinctly disappointing, especially for an international standard method and when the same standard procedure is followed. On account of this lack of agreement in the results by the different laboratories, one is forced to question the claim that the international pipette method is an absolute and reliable method for the mechanical analysis of soils.

If the hydrometer method could be tested by different laboratories as was the pipette method and the same procedure were followed, it seems reasonably

TABLE 2

Clay (0.002 mm.) as obtained by different laboratories on the same soils by means of the pipette method and following the same procedure

SOILS	LABORATORIES									
	Bangor	Belvederestraat	Brno	Glen Osmond	Kuala Lumpur	Leningrad	London	Oxford	Rothamsted	Zagreb
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
1. Brno, Rednzina	66.5	60.1	64.7	65.0	24.0	69.6	63.8	49.1	68.8	60.3
2. Brno, Alluvial	30.7	29.6	29.1	30.1	34.0	33.0	30.4	27.9	32.1	29.7
3. Budapest-Szik	33.3	33.2	35.6	36.4	36.0	39.0	33.5	26.5	35.5	30.2
4. Zagreb	31.3	29.2	27.6	30.2	34.0	....	32.0	27.2	33.0	27.6
5. Khartoum-Gezira	51.0	48.3	43.7	58.1	6.0	58.0	61.4	27.4	62.2	41.5
6. Khartoum-Alluvial-Kassala	36.2	32.8	36.7	45.2	34.0	48.1	49.0	33.1	45.6	26.0

assured that the results would agree surprisingly and certainly no such wide variation would occur as shown in table 2. The reason for this is that the hydrometer method is very simple, rapid, well-standardized, free of the personal element of the operator, requires no technique such as the pipette method does, and consequently the results can be easily duplicated.

Because the hydrometer method in its operation does not follow or is not in accord with certain physical laws covering hydrometer behavior, it has been criticized by some. But when the results of tables 1 and 2 are taken into consideration these criticisms are neither warranted nor supported by actual facts. It is important to realize that the error that may be caused by the hydrometer instrument itself is insignificant to the great errors that are caused in some soils by not using the exactly proper reagent to disperse them and to stabilize them. As has been abundantly shown, when ammonia, sodium hydroxide, sodium oxalate, and potassium hydroxide are used for reagents, markedly different

results are obtained in some soils. Here lies probably one of the most important problems in the mechanical analysis of soil, viz., to find the proper dispersing and stabilizing reagent that will work absolutely the same in all soils.

In view of all these facts it would seem, therefore, that on the whole the hydrometer method gives results as good as, if not better than, the pipette method, and for the average individual it will give more reliable results than the pipette method. In addition, the hydrometer method will do the work from thirty to forty times faster than the pipette method with very little effort on the part of the operator.

The hydrometer method has received a very thorough and extensive investigation by the United States Bureau of Public Roads (7) and with certain modifications and refinements this bureau has adopted the hydrometer method as its official method.

The hydrometer method has received constant attention with the idea of improving it. The final procedure as developed up to date for making mechanical analysis of soils by the method is as follows: Add 50 gm. of fine-textured soils or 100 gm. of the sand, based on oven-dry condition, to the dispersing cup (plate 1). Fill the cup with distilled water to about 1½ inches from the top. Add to the contents 5 cc. of a solution of normal sodium silicate or water glass (7) having a hydrometer reading of 36 at 67°F. If the soil is in lumps, sufficient time must be given to slake and to soak. As a matter of fact, it is well to allow all soils to soak for about 15 minutes before dispersing them. The soils should always be air dry, because in the wet condition they do not slake. The soaking can be done in a separate vessel and the material then washed into the cup. Then connect the cup to the stirring motor, and stir the contents for 5 minutes in the case of sands and 10 minutes in the case of all other soils. Those soils, however, which are recognized as difficult of dispersion should be dispersed for 20 to 30 minutes or longer. The sands should not be stirred more than 5 minutes because they seem to undergo abrasion.

Pour and wash the contents into the special cylinder. If 50 gm. of soil are used, fill the cylinder to the lower mark with the hydrometer in it. If 100 gm. of soil are used, fill it to the upper mark with the hydrometer in it. Only distilled water should be used. Then take the hydrometer out, place the palm of one hand on the mouth of the cylinder and shake the contents vigorously, turning the cylinder upside down and back several times. Place the cylinder quickly on the table and note the time immediately. Then at the desired period put the hydrometer in the suspension column, record the reading, and then take it out again. There is a tendency for slight amounts of soil material to settle on the shoulder of the hydrometer, and it is better not to leave it in continuously for all readings. Each time the hydrometer is used it should be clean.

At every hydrometer reading the temperature of the suspension should be measured. Great care must be taken, however, not to disturb too much the suspension column in putting in and taking out the hydrometer and the ther-

mometer. For every 1°F. above or below 67°F. apply a temperature correction of 0.2 graduation on the hydrometer. This temperature correction, however, is only an approximation, as it tends to vary somewhat with extreme concentrations of soil suspensions and also with extreme variations of temperature. Probably the most accurate hydrometer readings are taken near the temperature of 67°F., which is the temperature at which the hydrometer was calibrated in actual soil suspensions. Extreme temperatures such as 100°F. and 50°F. should be avoided. If possible, temperatures should be above 67°F. rather than below. For temperatures above 67°F. the corresponding amount of correction is added to the hydrometer reading, and for temperatures below 67°F. the corresponding amount is subtracted. The corrected hydrometer reading is then divided by the weight of soil taken and multiplied by 100, the result being the percentage of material still in suspension.

The hydrometer method cannot subdivide the sands into their various fractions, but can only determine their combined or total amount. Various experimental tests seem to show that the total combined sands of a soil can be ascertained more accurately by taking a hydrometer reading at the end of 40 seconds. A correct reading can be easily made in this short period except in some organic soils which have a tendency to produce froth on the top of the column after being shaken, in which case a correct hydrometer reading is not always possible. One way to overcome this difficulty is to blow at the froth, which tends to disappear quickly. The determination of the combined sand should be considered only as approximately correct.

The hydrometer was calibrated in actual soil suspensions consisting of an average loam soil. Its readings, therefore, are quite accurate. It was found very difficult to calibrate the range from 0 to 10 gm. per liter, however, and readings in this range are not so accurate as in the rest of the range. In this range readings are about 1 gm. per liter too high. It is advisable, therefore, to subtract 1 gm. per liter from all hydrometer readings below 9.9 gm. per liter before correcting for temperature.

A unique feature of the hydrometer method is the fact that the personal element is reduced to a minimum. One cannot but obtain correct results if one watches for one important thing, namely, the condition of the paddle on the stirring rod. Practically the whole success of the hydrometer method depends upon a complete dispersion of the soil, and a complete dispersion can be obtained only when the paddle on the stirring rod or shaft is in good condition. The paddle that has been used heretofore in the method wears out very easily and becomes flat and small. In this condition its efficiency is practically gone and the soils are not properly dispersed and consequently the results are not correct. In order to eliminate this serious weakness in the method, a new paddle or button has been adopted and placed on the stirring rod. When this paddle becomes worn it can be unscrewed from the shaft and replaced with a new one. This new arrangement, besides providing a paddle that is wear-resistant, also obviates the necessity of having to change the

stirring rod in order to change the paddle as has been the case heretofore. The paddles are very inexpensive and can be changed very frequently. It is strongly urged upon all those who are now using the old stirrer to replace it with the new one shown in plate 1.

Another extremely important point is that the cup should have baffles in it. Without the baffles the soils cannot be dispersed easily.

To calculate the conventional amount of combined sand (1.0–0.05 mm.), silt (0.05–0.005 mm.), and clay (0.005–000 mm.) and the finer clay (0.002–000 mm.) as determined by the hydrometer method, the procedure is as follows:

The corrected hydrometer reading at the end of 40 seconds is divided by the amount of absolute dry soils taken and is multiplied by 100. The result is percentage of material still in suspension at the end of 40 seconds. This percentage is subtracted from 100 and the result is the percentage of material that settled out at the end of 40 seconds, which is supposed to represent all the sand in the soil. The corrected hydrometer reading at the end of 1 hour is also divided by the weight of soil sample and multiplied by 100. The result is percentage of material still in suspension and is considered to be the conventional clay (0.005–000 mm.). The percentage of the conventional silt is obtained by subtracting the clay from 100, and from this result subtracting again the percentage of sand. To obtain the finer clay (0.002 mm.), it is only necessary to divide the correct hydrometer reading at the end of 2 hours by the weight of the soil sample and multiply by 100. The organic matter content and the carbonate content are not determined by the method.

It is thus seen that by means of the hydrometer method almost a complete mechanical analysis of soils can be made in only 1 or 2 hours, with the expenditure of very little time and effort.

From all studies and examinations thus far made, it seems that the hydrometer method is reasonably accurate and reliable on all soils that are properly dispersed and properly stabilized by the reagent. It seems to be especially accurate in the coarse clay fraction (0.005 mm.). In the finer clay portion (0.002 mm.) it may not be so accurate in some soils that have a very large amount of their finer material just slightly above the 0.002-mm. size. In such soils the hydrometer method indicates a larger content of the 0.002-mm. fraction than the pipette method, but the difference may not be very large.

In peats and mucks the hydrometer method is not very reliable, first, because these materials are almost impossible to disperse, and second, because they have a smaller specific gravity and the hydrometer was calibrated on average normal loam soils. The method, however, seems to be quite accurate on mineral soils containing a moderately high organic matter content, provided the latter is well decomposed and is completely dispersed. As previously shown (5), mineral soils containing a very high organic matter content in an incompletely decomposed state should be first treated with hydrogen peroxide. Mineral soils containing no, or only small amounts of, well-decomposed organic matter need not be treated with hydrogen peroxide.

It is advisable to wash very alkaline soils before using them for analysis, or a correction should be applied for the salts if present in appreciable amounts.

By taking hydrometer readings continuously or every so often, a complete distribution curve of size particles of soils and their respective amounts can be readily and very reliably obtained.

The hydrometer method, therefore, would seem to give most, if not all, of the essential information required for all practical purposes, and because of its great rapidity, simplicity, and reasonable accuracy, it should meet a great need.

SUMMARY

With the coöperation of the United States Bureau of Chemistry and Soils, the hydrometer method for the mechanical analysis of soils was examined and compared with the pipette method.

It was found that what the pipette method determines as coarse clay (0.005 mm.) the hydrometer would determine at the end of 1 hour, and what the pipette method determines as fine clay (0.002 mm.) the hydrometer method would determine at the end of 2 hours.

The results obtained show that the two methods agree exceptionally well on the determination of the coarser clay (0.005 mm.). On the determination of the fine clay (0.002 mm.) they do not agree very closely on some soils but on the majority of soils they agree satisfactorily. The disagreement between the two methods in some soils seems to be due to differences in dispersion.

A new stirrer is now employed in place of the original one. In this new stirrer the paddle is made of hard steel and when it becomes worn, it can be unscrewed from the stirring rod and replaced with a new one.

On account of its great simplicity and rapidity, and its reasonable accuracy, it seems that the hydrometer method has many distinct advantages over all other methods.

On account of the many inquiries received as to the price of the hydrometer method outfit, and where it may be obtained, the following information is given:

The dispersing machine and cup, which cost about $22, are handled by the Hamilton Beach Company, Racine, Wisconsin.

The hydrometer and cylinder, which cost about $5, are handled by the Taylor Instrument Company, Rochester, New York.

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PLATE 1

THE DISPERSING MACHINE, SPECIAL CUP, SPECIAL CYLINDER, AND SOIL HYDROMETER
The paddle is screwed to the stirring rod and can be replaced when it becomes worn

PLATE 1

THE DETERMINATION OF PHOSPHATE AVAILABILITY IN CALCAREOUS SOILS BY ELECTRODIALYSIS

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It is possible to make a fairly reliable estimate of phosphate availability in many soils by one or several of the methods now in use. The limit of interpretation which can be made from the data is largely a matter of soil type, and since most chemical methods involve the use of acid solvents they are of limited or doubtful value for calcareous soils. By electrodialysis it is possible to extract the soluble, and to a large extent the available, phosphate with less interference in calcareous soils than in non-calcareous types. Phosphate is present in calcareous soils largely as carbonato-apatite. In the presence of an excess of CO_3 ion and solid phase $CaCO_3$ the solubility of this compound is reduced to zero, whereas it is appreciably soluble at slight concentrations of hydrogen ions, such as that produced by free CO_2 in the soil solution.

In a recent study of electrodialysis (3), conducted in this laboratory, it was shown that soil phosphate is readily dissolved by this procedure and that there is a close relation between the rate of electrodialysis and the performance of the soils in plant tests. In fact, over a definite period of time the specific solution rate of phosphate is a remarkably constant value for each soil. Absorption of phosphate by plants takes place largely or entirely as the H_2PO_4 ion, which is the dominant ion formed by ionization of phosphates at reactions below pH 6.8. It is of interest in this connection that the most satisfactory chemical methods of determining availability are those in which slightly acid solvents, preferably buffered at a low hydrogen-ion concentration, are utilized. This condition can be accomplished, in calcareous soils, only by electrodialysis. When a calcareous soil is electrodialyzed in a three-chamber cell there is a rapid reduction in pH of the soil-water mixture in the middle chamber. In spite of the excess of $CaCO_3$ present the pH can be reduced to pH 4.0 even though the soil-water mixture is continuously agitated with a stream of air. This indicates that electrodialysis closely imitates the plant roots in extracting phosphate from soils, because within the root-soil contact zone the root itself creates a low pH by secretion of CO_2. It also imitates the buffered dilute acid solutions used to dissolve available phosphate from non-calcareous soils.

In our investigations phosphate (3) was determined in the anode solution by the molybdenum-blue method, and it was found that a current of 0.2 ampere was best suited for yielding determinable amounts. It was observed that regardless of the amount of current flowing, when 10 gm. of soil was used, and

provided the electrodialysis was continued long enough, the curve obtained, by plotting time against phosphate extracted, became practically horizontal. This suggested that the amount of phosphate which can be removed from a soil by electrodialysis is a constant for any amperage, and we therefore extended our studies along this line.

EXPERIMENTAL

Phosphate removed by constant amperage and variable weight of soil

The apparatus used was essentially that of Mattson, as described in a previous publication, and is similar to that used by Harper (2), except that we used 1 liter of water in each of the electrode chambers and 100 cc. in the middle chamber. A cathode of sheet copper, 7 x 10 cm., and an anode of platinum gauze, 5 x 12.5 cm., were used. As a source of current a 2–12 volt rectifier was attached to the lighting circuit. Adjustable resistance was inserted to maintain a constant flow of current at 0.2 ampere, and electrodialysis was continued until the analysis of the solution in the anode chamber showed that no further phosphate was being removed from the soil. This required 4 to 8 hours.

TABLE 1

PO_4 removed from 1, 2.5, 5, 10 gm. portions of soil by .2 ampere

Expressed as milligrams PO_4 per 10 gm. soil

SOIL NO.	10 GM. SOIL	5 GM. SOIL	2.5 GM. SOIL	1 GM. SOIL
1	17.4	17.0	18.0	17.5
2	....	12.0	14.8	15.0
3	4.0	5.0	6.0	5.0
4	6.1	8.0	8.0	....
5	12.0	11.6	11.8	12.0
6	7.0	6.8	7.2	8.0

The soils selected for this experiment were all calcareous soils. The results obtained are given in table 1 and are calculated to a basis of milligrams PO_4 per 10 gm. soil, although the actual amounts of soil used were 1, 2.5, 5, and 10 gm.

These data show that, provided the amount of current flowing is a constant, all soils contain a definite amount of phosphate which can be brought into solution when they are subjected to electrodialysis.

Phosphate removed by variable current from a definite weight of soil

Having shown that the amount of phosphate which can be removed from soils by 0.2 ampere is a constant for every soil, we next varied the current and kept the weight of soil constant. Two grams of soil was used in all cases and the amount of current varied between 0.1 and 1.0 ampere, a rectifier being used for the small flow of current and a motor generator for the greater flow. As in

the preceding experiment, the electrodialysis was continued until the phosphate concentration of the anode chamber had reached a constant. From the group of calcareous soils studied two representative samples are selected, one of which is low and the other high in electrodialyzable phosphate. The amounts of phosphate extracted by electrodialysis at several variations in amperage are given in figure 1.

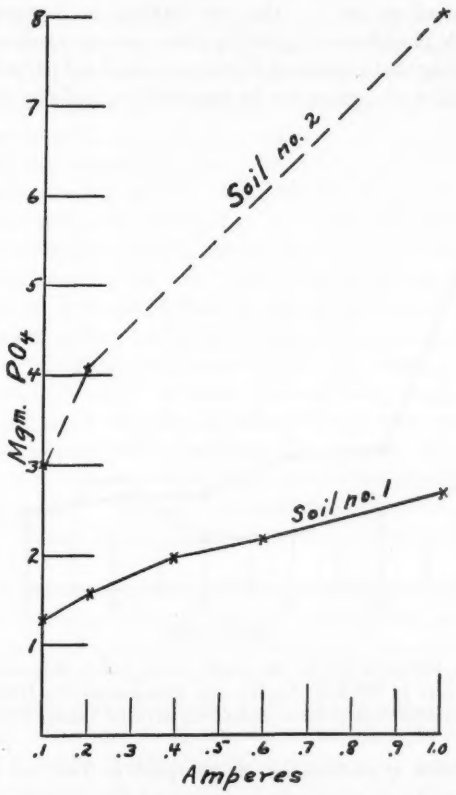


FIG. 1. TYPICAL EXAMPLES OF THE EFFECT OF AMPERAGE ON PHOSPHATE EXTRACTED BY ELECTRODIALYSIS FROM A POOR SOIL, NUMBER 1, AND A GOOD SOIL, NUMBER 2

This experiment shows that the amount of phosphate which can be withdrawn from a soil by electrodialysis depends upon the amperage, and that flow of current must be carefully controlled if the analyses are to be comparative. There is evidence that the rate of increase in solubility with increase in flow of current may serve as a measure of the supplying power of the soil. Soil No. 1 shows a low initial solubility at 0.1 ampere and a low supplying power, as

measured by increase in flow of current. In this soil the amount of phosphate dissolved by 1.0 ampere is twice that removed by 0.1 ampere. Soil No. 2, which is well supplied with available phosphate, shows a higher initial yield at 0.1 ampere and a greater increase as the flow of current is increased up to 1.0 ampere. It is believed that the phosphate removed by 0.1 ampere represents the liquid phase and the easily soluble solid phase phosphate, such as di-calcium phosphate, following which the carbonato-apatite is extracted. This suggestion is based on the fact that we obtained no increase in amount of electrodialyzable phosphate by grinding these same two soils in a ball mill for 100 hours, showing that fineness of division or size of soil particles is not related to the rate at which phosphate can be removed from soils by this procedure.

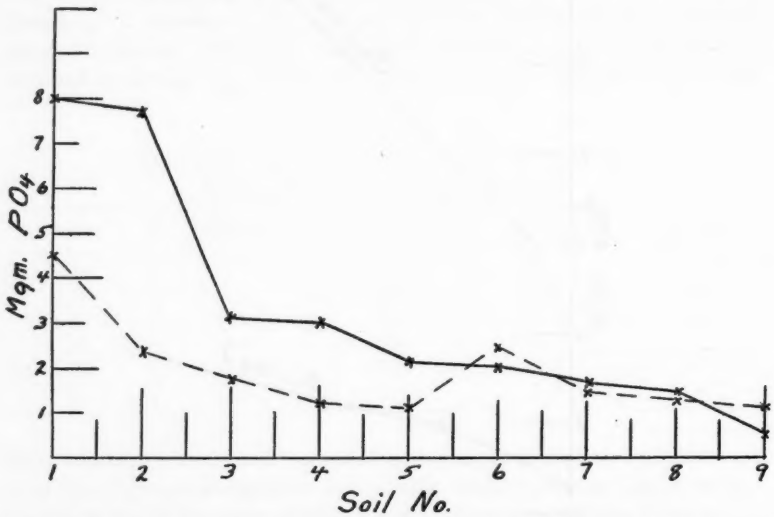


FIG. 2. RELATION BETWEEN NEUBAUER VALUE (SOLID LINE), MILLIGRAMS PO_4 REMOVED FROM 100 GM. SOIL BY 100 RYE PLANTS, AND MILLIGRAMS PO_4 (BROKEN LINE) EXTRACTED FROM 2 GM. SOIL BY ELECTRODIALYSIS WITH 0.2 AMPERE FLOW OF CURRENT

Relation of electrodialyzable phosphate to Neubauer values

The preceding data, together with our previous investigations (3), have led us to believe that for calcareous soils it is not necessary to use a current of more than 0.1 ampere, or 0.2 ampere at the most, and that a 2 gm. sample of soil is sufficient to yield readily determinable amounts of phosphate. On this basis nine calcareous soils were selected. The amount of phosphate withdrawn by a current of 0.2 ampere from 2 gm. of soil was determined, as was also the Neubauer value. These data are shown graphically in figure 2. A rather close correlation between Neubauer values and the amount of available phosphate as determined by electrodialysis is demonstrated.

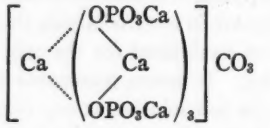
DISCUSSION

The soils used throughout these experiments have been calcareous soils, and therefore the method suggested is believed to be applicable only to such types, which, however, are the most prevalent types in the irrigated valleys of the Southwest. In other of our investigations (3, 4) we have used non-calcareous types as well as a number of phosphate minerals and noted wide variations in their rate and ease of dialysis. This is especially true in comparisons of calcium and iron or aluminum phosphates and the phosphate ions adsorbed by positive and negative colloids. Except for the ferrous phosphate, vivianite, the iron and aluminum phosphates do not yield their phosphate readily to solution when subjected to electrodialysis. Therefore electrodialyzable phosphate must be derived in most part from calcium and magnesium compounds, to a small extent from organic phosphate (4), and to a limited extent from phosphate adsorbed by the soil colloids. Since yield of phosphate to electrodialysis depends upon solubility and adsorption forces, the equilibrium, which represents maximum solubility for each different amperage, will vary with the magnitude of these forces in the soil. Also, since solubility reactions proceed toward equilibrium, if the products of the reaction are removed from the middle chamber of the cell as they are in electrodialysis, the solubility will proceed to the limit of the conditions established for the cell, which in this case is the amount of current flowing. It seems reasonable to assume that since the amount of phosphate in the soil solution at any one time is a function of the solubility of the chemical forms present and the nature of the soil colloids, particularly the charge upon the colloid, these factors directly determine the supplying power of the soil. Therefore, if electrodialysis measures these processes it must closely imitate the existing forces which function in the feeding operations of the plant.

In discussing the value of electrodialysis too much emphasis cannot be placed upon the limitation which variation in soil type places upon the process. Our own work suggests the separation of soils into three groups according to the reaction of the soil; namely, acid soils, neutral soils, and alkaline soils. Since iron and aluminum phosphates, as well as the phosphate absorbed by hydrated oxides of iron and aluminum, do not react readily to electrodialysis (4) when a 2 gm. sample is subjected to a current of 0.2 ampere, it should be necessary to use in such soils a greater flow of current as well as a larger sample of soil. Even then it is doubtful whether appreciable solution of phosphate can be obtained. Iron and aluminum phosphates are least soluble at reactions between pH 4.0 and 7.0, and since the soil in the central chamber of the cell is maintained at low pH it is self-evident that conditions in the cell will not promote increased solubility of phosphate during electrodialysis of acid soils. Alkaline calcareous soils are best suited to this method because their phosphate is largely present as carbonato-apatite. The solubility of this compound is greatly increased when the pH of the soil is lowered below pH 7.0, and thus far not a single calcareous soil has been met which has not yielded readily

determinable amounts of phosphate when 2 gm. of soil are electrodialyzed at 0.2 ampere. The third group of soils, those within the immediate range of pH 7.0, probably contain all the aforementioned forms of phosphate but would doubtless require a larger sample of soil and possibly a stronger flow of current for electrodialysis than an alkaline calcareous soil.

It is of interest in this connection to compare some of our data with those of Harper (2), whose studies on electrodialysis of soils showed that with few exceptions soils yielding less than 30 p.p.m. phosphorus (equivalent to 90 p.p.m. PO_4) were deficient, that is, gave response to phosphate fertilization. This is equivalent to 0.9 mgm. PO_4 per 10 gm. soil. When this is compared with 7.0 mgm. PO_4 per 10 gm. soil for a calcareous soil (soil No. 6, table 1), which gives marked response to phosphate fertilization, it is difficult for one not familiar with alkaline calcareous soils to conceive of a deficiency. This comparison is inserted merely to emphasize the influence of soil type on rate of dialysis and then, in turn, the relation of this rate to availability as measured by plant behavior. The reason for poor availability in calcareous types is best illustrated by the formula for carbonato-phosphate which is given by Gassmann and Werner (1) as



It may be readily understood from this formula why the solubility of this compound is reduced to zero in the presence of solid phase $CaCO_3$ and an alkaline reaction, and why the presence of an excess of CO_2, or the presence of H ions, increases the solubility.

There is still another difference between calcareous alkaline soils and non-calcareous types which is important and which may influence the amount of phosphate obtained by electrodialysis. Reference is made to the conductivity or the capacity of different soils to carry a flow of current. An alkaline calcareous soil will conduct a flow of 1.0 ampere very readily and will require little change in resistance throughout an 8 hour period, whereas a non-calcareous soil will carry 1.0 ampere only for a very short initial period, after which it cannot be maintained above 0.2 ampere even when the current is increased to 60 D. C. volts. Although the amperage may be raised by addition of $CaCO_3$ to the middle chamber, the effect is only temporary and has no influence on the amount of phosphate brought into solution. The steadiness of current flow in calcareous soils is a point in favor of the adaptability of the electrodialysis method to this type.

CONCLUSIONS

Electrodialysis is admirably suited to the determination of available phosphate in alkaline calcareous soils because the pH of the soil-water mixture

can be reduced to as low as pH 4.0 in spite of the excess of $CaCO_3$ which is present.

The percentage of phosphate which can be extracted by electrodialysis is a constant value for every soil regardless of the amount of soil used. On the other hand, the value varies with the amount of current flowing, and amperage must be controlled by adjustable resistance to produce comparative results.

There is a close relation between Neubauer values and amount of phosphate removed from soils by electrodialysis.

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THE ARSENIC CONTENT OF SOILS

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Large quantities of arsenic are used annually in the spraying of fruit, sugar beets, alfalfa, cotton, and other crops. Arsenic is also being used to a limited extent for killing weeds. Most of this arsenic finds its way into the soil. In addition to this, Kunkel (19) found arsenic in many rocks and waters. Later investigators (2, 3, 8, 23, 25) have shown it to be present in appreciable quantities in the surface and underground waters of some regions. Czapek (6) states that traces of arsenic are nearly always present in soil. It has been found so frequently in soil by some investigators (24, 28) that they have come to refer to it as a "normal" constituent of "soil." Herzfeld and Lange (18) found arsenic in certain raw sugars and traced it to the limestone which had been used in the manufacture of the sugar. Headden (17) found some virgin prairie soils relatively rich in arsenic; this is in accord with the findings of the author (10) who found arsenic in virgin soil to the extent of 4 p.p.m. It did not result from smelter smoke or similar sources, and, as reported by Headden in his investigations, was derived from the decay of native rock.

Arsenic not only occurs in soil but, because of methods of application and fixation by bases, tends to accumulate in the surface soil (20, 24, 28). Headden (16) found arsenic in some cultivated orchard soils to the extent of 138 p.p.m. and he believes that in many places the accumulation is so great as to render it injurious to vegetation. Cooper and his co-workers (5) found that the application of small quantities of arsenic to light soils decreased yields of cotton and cowpeas. On the other hand, Stewart and Smith (26) produced no injury to peas, radishes, wheat, beans, and potatoes until large quantities of soluble arsenic were applied to a highly calcareous soil. Francois (7) considers that there is little danger of the earth becoming unfit for vegetation from the proper use of insecticides, which is in keeping with the conclusions of Ball and his co-workers (4). Grunner (14), who found arsenic to the extent of from 0.026 per cent to 1.426 per cent in the Reichensterm soil, is not so optimistic. Priezker (22), in the analysis of a soil near Basel, Germany, states that it contained from 0.09 to 0.168 per cent of arsenic trioxide, which was conspicuous for its poisonous effect on vegetation and animals.

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[2] Contribution from department of bacteriology and chemistry. Publication authorized by director, November 26, 1933.

The study of arsenic-decomposing fungi by Thom and Raper (27) and their claim that the fungi will keep down the concentration of arsenic in the soil give to the subject a brighter outlook, for if arsenic does not accumulate in soil the likelihood of injury is slight. Moreover, the quantity of arsenic in the soil does not determine its toxicity, but rather its toxicity is determined by its solubility, which is dependent upon the chemical and biological properties of the soil.

It is evident from this brief review of the literature that the quantity of arsenic accumulating in a soil and its toxicity to plant life have not been fully determined; yet the solution is of vital economic importance to permanent agriculture. Therefore, this investigation has been conducted in the hope that some light might be shed on the quantity of arsenic occurring in some soils, its solubility, and the factors influencing its solubility. Total arsenic and water-soluble arsenic, as well as the soluble salt content of some fifty widely different soils, are reported in this paper.

METHODS

The total arsenic was obtained by extracting the soil with nitric and sulfuric acid and determining the quantity of arsenic by the Marsh method, modified so that iron did not interfere (9). The water-soluble arsenic and soluble salts were determined by extracting for eight days 500 gm. of soil with 2,000 cc. of CO_2-free water. The arsenic was determined by the Marsh and the soluble salts by standard methods. All determinations were made in triplicate and results averaged. In order to economize on space, only the summarized results are given. These bring out the principal facts, but it must be borne in mind when interpreting them that the maximum and minimum as given in the tables for total arsenic, soluble salts, carbonates, chlorides, sulfates, nitrates, organic nitrogen, and calcium do not necessarily correspond for the specific soil for maximum and minimum water-soluble arsenic.

The total arsenic of the soil varies from 7.2 to 367.2 pounds of arsenic per acre-foot. An acre-foot was taken as 3,600,000 pounds. Eight of the soils tested carry over 200 pounds per acre-foot of arsenic, and over one-third of them contained more than 100 pounds of arsenic per acre-foot of soil. Thus, in some of the soils a remarkably large quantity of arsenic has accumulated. This is evidence that arsenic is accumulating in these soils; unfortunately, the quantity of arsenic which has been applied to these soils is not known. Consequently, it has been impossible to check the theory of Thom and Rogers that some molds change soil arsenic to arsine and hence limit its accumulation in soil. It is, however, evident from these results (table 1) that large quantities of arsenic may, and at times do, accumulate in some soils.

Even the arsenic occurring in these soils may not be injurious to microbial and plant life, since it has been shown that from 60 to 100 pounds per acre-foot of arsenic as lead arsenate may stimulate microbial activity in a highly calcareous soil, and it requires from 600 to 700 pounds to reduce bacterial activities

greatly (12). However, small quantities in a light soil, low in calcium and iron, and especially when the arsenic is applied as Paris green or an arsenite, may produce marked injurious effects (11, 12, 13). The same results hold for some higher plants. Stewart and Smith (26) failed to injure plants by applying 100 pounds of disodium arsenate to an acre of highly calcareous soil, whereas Cooper and his co-workers (5) injured cotton and cowpeas with quantities as low as 50 pounds per acre when applied to light soil. In neither case is the quantity of water-soluble arsenic actually occurring in the soil given.

The water-soluble arsenic in some of the soils under consideration is appreciable, varying from 0.7 to 31.9 pounds per acre-foot of soil. Four soils carry over 20 pounds per acre-foot of water-soluble arsenic and 18 contain 9 pounds or over.

TABLE 1

Summary of water-soluble arsenic and total arsenic found in 50 soils

Pounds per acre

	WATER-SOLUBLE ARSENIC	TOTAL ARSENIC
Maximum	31.9	367.2
Mean	8.5	101.6
Minimum	0.7	7.2
Coefficient of Correlation	0.4214 ±0.0762	

The correlation coefficient between water-soluble arsenic and total arsenic has been calculated (21) according to the formula

$$r = \frac{(x_1 y_1)}{N\sigma_1 \sigma_2}.$$

where r is the correlation between the two variables x and y, of which σ_1 and σ_2 are the respective deviations and N is the number of pairs of variables; x_1 and y_1 are deviations from the means of x and y, respectively.

The probable error has been calculated by the formula:

$$\text{P.E.} = \frac{.67449\ (1 - r^2)}{N}$$

The number of determinations used in the calculations is probably too limited for most satisfactory results, but the individual determinations are the averages of three determinations, hence are based on 150 determinations. However, the results must not be considered as final but rather indicative of what may be expected, subject to modification when more extensive work can be done.

The correlation between total arsenic and water-soluble arsenic = 0.4214 ±

0.0762, thus indicating that the water-soluble arsenic is a function of the total arsenic in the soil. However, there are cases in which the total is high and the water-soluble arsenic low and vice versa, thus indicating that factors other than mere quantity of arsenic in soil govern its solubility. Stewart and Smith (26) found the solubility of lead arsenate to be greatly increased by many common salts when these are present in the aqueous solvent, but sulfates and nitrates apparently do not increase materially the solvent power of water for lead arsenate. Acid salts and those which hydrolize with an alkaline reaction markedly increase the solvent action of water on lead arsenate. Hence, one may expect the solubility of soil arsenic to be a function of the chemical nature of the soil which is reflected by the soil constituents held in the liquid phase.

TABLE 2

Summary of water-soluble arsenic and total water-soluble salts found in 50 soils

Pounds per acre

	WATER-SOLUBLE ARSENIC	TOTAL WATER-SOLUBLE SALTS
Maximum	31.9	45,000
Mean	8.6	8,511
Minimum	0.72	1,732
Coefficient of Correlation	-0.0274 ± 0.0961	

TABLE 3

Summary of water-soluble arsenic and sodium chloride found in 50 soils

Pounds per acre

	WATER-SOLUBLE ARSENIC	SODIUM CHLORIDE
Maximum	31.9	3,024.0
Mean	8.5	405.7
Minimum	0.72	18.0
Coefficient of Correlation	0.0907 ± 0.0954	

Water-soluble salts of these soils varied from 1,732 to 45,000 pounds per acre-foot (table 2). All except four of these soils had less than 21,000 pounds of soluble salts; the four soils carrying quantities greater than 21,000 pounds contained from 3 to 15 pounds per acre of soluble arsenic, whereas another soil containing 6,000 pounds per acre of total soluble salts carried 33 pounds per acre of soluble arsenic. The value of r in this series $= 0.02739 \pm 0.0961$, indicating that it is not the total quantity of soluble constituents within the soil but the predominance of specific chemical compounds which governs the solubility of the arsenic.

The sodium-chloride content of the soils varied from 18 to 3,024 pounds per acre-foot of soil (table 3), all except four containing less than 1,000 pounds per

acre-foot. The soils carrying the largest quantities of soluble arsenic are often those which contain the smallest quantities of sodium chloride. In this series $r = 0.0907 \pm 0.0954$.

All soils used contained appreciable quantities of sodium carbonate, the highest carrying 3,831 pounds per acre-foot (table 4). Probably sodium car-

TABLE 4

Summary of water-soluble arsenic and sodium carbonate found in 50 soils

Pounds per acre

	WATER-SOLUBLE ARSENIC	SODIUM CARBONATE
Maximum	31.9	3,831
Mean	8.6	1,451
Minimum	0.72	579
Coefficient of Correlation	0.1379 ±0.0927	

TABLE 5

Summary of water-soluble arsenic and sulfates found in 50 soils

Pounds per acre

	WATER-SOLUBLE ARSENIC	SULFATES
Maximum	31.9	2,372.0
Mean	7.8	500.0
Minimum	0.72	64.8
Coefficient of Correlation	−0.0592 ±0.1024	

TABLE 6

Summary of water-soluble arsenic and calcium oxide found in 50 soils

Pounds per acre

	WATER-SOLUBLE ARSENIC	CALCIUM
Maximum	31.9	6,290
Mean	8.6	1,618
Minimum	0.72	126
Coefficient of Correlation	0.0523 ±0.0960	

bonate increases slightly the solubility of arsenic, whereas calcium, iron, and magnesium carbonate would depress the solubility. The correlation coefficient in this series is only 0.1379 ± 0.0927.

Thirty of the soils contained 1,000 pounds or less of sulfates per acre-foot (table 5). Apparently, sulfates have little effect on the solubility of the arsenic, for the value of r was found to be -0.0592 ± 0.1024.

Most of the soils contain appreciable quantities of calcium, which one would expect to decrease the solubility of the arsenic, since arsenic is found to be less toxic to plants and soil microörganisms in a calcareous soil than in a non-calcareous soil (table 6). Usually these soils have the smallest quantities of water-soluble arsenic. The value of r in this series was found to be $= 0.0523 \pm 0.0960$. Some of these soils carry large quantities of nitrates, which apparently increase the solubility of the arsenic, for r was found to equal 0.2781 ± 0.0939 (table 7).

The organic nitrogen content of the soils was usually rather low, with no evidence that it tends to increase the solubility of the arsenic (table 8). At times

TABLE 7

Summary of the water-soluble arsenic and nitrates found in 50 soils

Pounds per acre

	WATER-SOLUBLE ARSENIC	NITRATES
Maximum	31.9	1,783
Mean	8.5	752
Minimum	0.72	130
Coefficient of Correlation	0.2781 ±0.0939	

TABLE 8

Summary of the water-soluble arsenic and organic nitrogen found in 50 soils

Pounds per acre

	WATER-SOLUBLE ARSENIC	NITROGEN OTHER THAN NITRATES
Maximum	31.9	12,343
Mean	8.5	4,529
Minimum	0.72	1,099
Coefficient of Correlation	0.0542 ±0.0933	

the soils having the largest quantity of organic nitrogen contained the smallest quantities of water-soluble arsenic.

SUMMARY

Fifty orchard soils, varying widely in chemical, physical, and biological properties, were analyzed for total arsenic, water-soluble arsenic, and various soluble salts. Total arsenic varied from 7.2 to 367.2 pounds per acre-foot of soil, thus indicating that large quantities of arsenic may accumulate in soil. The water-soluble arsenic varied from 0.7 to 31.9 pounds per acre-foot of soil. It is probable that the toxicity of arsenic to plants and to soil microörganisms is governed by the solubility of the soil arsenic. Hence, the correlation be-

tween various soluble salts and soluble arsenic in the soil was determined. The limited number of soils analyzed, together with the high probable error, makes the conclusions merely tentative. No correlation was found to exist between water-soluble arsenic and total soluble salts, sodium chloride, sulfates, calcium carbonate, and organic nitrogen of the soil. A slight correlation was found to exist between the water-soluble arsenic and sodium carbonate and nitrate.

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FUNCTIONAL RELATIONSHIPS BETWEEN SOIL PROPERTIES AND RAINFALL

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The study of functional relationships between soil properties and soil forming factors permits the establishment of numerical laws of soil formation and will serve as a basis for the formulation of quantitative theories. Approaching soil formation from the viewpoint of a dynamic chemical system one would postulate that in correlating soil properties with rainfall all of the other soil forming agencies should remain constant. It is doubtful whether such an ideal system can be found to any great extent under natural conditions, but a few regions in the United States approach rather closely the goal set. One such region is represented by the arid-humid transition belt which extends from Colorado through Kansas to western Missouri.

CHARACTERIZATION OF THE AREA INVESTIGATED

The main soil forming factors operative in the area selected can be characterized as follows:

Moisture. The annual *precipitation* varies from 14 inches (35.6 cm.) in the semi-arid to about 38 inches (96.5 cm.) in the humid districts. For the region in question a very simple relation happens to exists between precipitation and N. S. Quotient (Meyer's ratio) which can be stated as follows:

$$\text{N.S.Q.} = 7.8R$$

where R represents annual rainfall in inches.

The normal *seasonal variation* of rainfall is consistent throughout the area and belongs to the so-called "plains type" which is characterized by dry winters and marked concentration of rainfall in the late spring and summer months.

Rainfall and N. S. Quotient do not take into consideration the water losses due to *runoff*. The relation of runoff to rainfall for the principal water-sheds of Kansas is known (5) and has the form

$$\varphi = 0.0037\ R^2 \qquad (A)]$$

[1] Contribution from the department of soils, Missouri Agricultural Experiment Station, Journal series No. 372.

[2] This agreement is remarkable indeed because the previous surface samples were collected by different persons in different localities.

where φ represents annual runoff in inches and R the annual precipitation in inches. With the aid of equation (A) the data in table 1 have been calculated and will be used in the interpretation of the soil property-rainfall curves.

Temperature. In order to keep temperature constant the soil samples were selected along an annual isotherm which has an average value of 52°F. (11.1°C.) for the states of Kansas and Missouri. The individual stations vary between 51.7°F. (10.9°C.) and 54.4°F. (12.4°C.). A few localities in Colorado report somewhat lower values, namely, 47–50°F. (8.3–10.0°C.).

Vegetation. Except for a limited number of virgin soils in Colorado and western Kansas, all samples were taken from pastures or cultivated fields. In all instances, however, the original vegetation consisted of grass. According to the map by Shantz (7) the prairie types listed in table 2 are dominant.

TABLE 1

Relation between runoff and rainfall in Kansas

	RAINFALL IN INCHES			
	10	20	30	40
Runoff in inches	0.4	1.5	3.3	5.9
Runoff in per cent of rainfall	4	7.5	11.0	14.8

TABLE 2

Nature of vegetation in the region studied

REGION	VEGETATION	APPROXIMATE RAINFALL	
		inches	*cm.*
Eastern Colorado	Grama Buffalo grass	Below 17	Below 43
Western Kansas	Wire grass	17–21	43–53
Central Kansas	Bluestem Bunch grass	21–27	53–70
Eastern Kansas and Western Missouri	Bluestem sod	27 to >38	70 to >97

According to measurements by Clements and Weaver and also on the basis of hay yields per acre the amount of organic matter produced increases regularly from west to east.

Parent Material. The entire region belongs to the great American loess belt which extends in a west-east direction over a distance of more than a thousand miles. The thickness of the smooth-surfaced loess mantle reaches in the western part in a few cases 30 to 40 feet, but mostly much less. In eastern Colorado it is perhaps more adequate to speak of wind-blown soils instead of loess, because of the coarser texture of many of the deposits. In eastern Kansas and western Missouri, the average thickness is in general much greater, and in some places near the Missouri River the loess is more than 100 feet thick. No samples were taken from the obviously young bluffs close to rivers.

In many localities, especially where the loess mantle is shallow, it is very difficult to determine the boundary between the loess and the *strata beneath.* The latter are of the following types:

Eastern Colorado and western Kansas: Tertiary deposits (Ogalolla formation) occupy all of the high plains. The materials are mainly sands in various degrees of fineness and more or less cemented by carbonate of lime. In some cases lime carbonate containing but little sand predominates.

Central Kansas: The tertiary deposits are followed by an extensive belt of the Cretaceous system, which is composed of clayey and sandy shales, chalky limestone, and sandstone, named in the order of their quantitative importance. In east central Kansas a narrow strip of the Permian system, consisting of marine shale, limestone, salt, gypsum, and sandstone, appears below the loess.

Eastern Kansas and western Missouri: The Pennsylvanian rocks composed of a series of alternating shale and limestone formations have been covered by the Kansan ice sheet. The drift deposited (now mostly covered by loess) is a heterogeneous mixture of clay, sand pebbles, and occasionally boulders. It is very much weathered and thoroughly oxidized, and the pebbles and boulders are decayed and soft. The thickness of the glacial drift is on the average not greater than 6–10 feet and in many places it is practically absent, but locally, as shown by well borings, there are accumulations of more than 60 feet.

TABLE 3

Data on topography of western Kansas

TOWN	MERIDIAN	ALTITUDE		DISTANCE		SLOPE	
		feet	*m.*	*miles*	*km.*	*feet/mile*	*m./km.*
Goodland	101° 41′	3,687	1,124	0	0		
						15.3	2.9
Colby	101° 02′	3,138	957	36	58		
						8.3	1.8
Dresden	100° 25′	2,731	832	80	129		
						13.2	2.5
Phillipsburg	99° 20′	1,939	591	140	225		
						4.6	0.9
Smith Center	98° 47′	1,800	549	170	274		
						1.0	0.2
Lebanon	98° 32′	1,812	552	182	293		

Topography. The route followed in taking the soil samples crosses the Great Plains which is an old plateau of remarkably uniform topography. In table 3 a typical section of western Kansas is listed, and it is seen that the altitude of the towns scattered over the plateau changes regularly and only slightly. Between the points selected the landscape is level or slightly undulating and occasionally rolling.

SOIL GROUPS AND CLIMATIC SOIL TYPES

The region embraces both the pedocals and the pedalfers, the boundary between the two occurring at a rainfall of about 27 inches (68.6 cm.) according

to Marbut's generalized maps (6). The isotherm followed runs through the important climatic soil types Chestnut soils, Chernozems, and Prairie soils. On the basis of Marbut's tentative maps their occurrence in Colorado, Kansas, and Missouri corresponds to the following annual rainfall data:

Chestnut soils: below 20 inches (50.8 cm.)
Chernozem soils: 20–27 inches (50.8–68.6 cm.)
Prairie soils: 27–40 inches (68.6–101.6 cm.)

Figure 1 shows the general arrangement of the major climatic soil types and the position of the 11°C. annual isotherm along which the samples were taken.

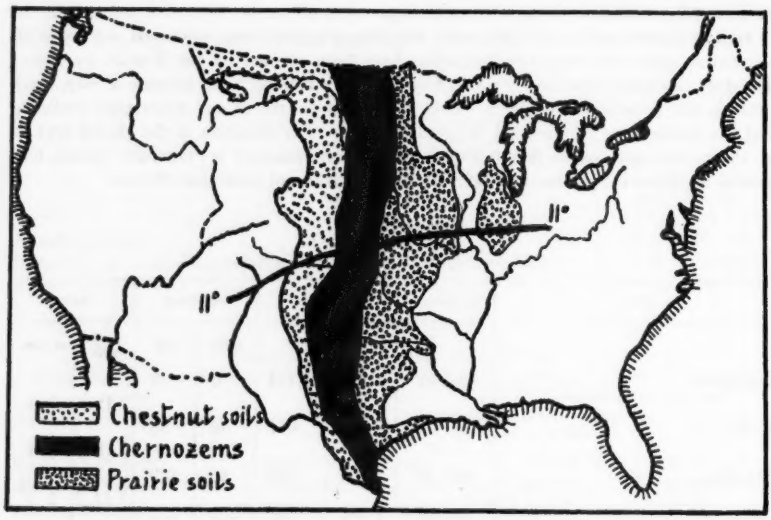

FIG. 1. CHESTNUT SOILS, CHERNOZEMS, AND PRAIRIE SOILS FORM NARROW BELTS EXTENDING FROM NORTH TO SOUTH

Note the location of the 11°C. annual isotherm along which the soil samples were collected

TECHNIQUE OF SAMPLING

In September 1931 about 100 surface samples (0–7 inches deep) were collected at intervals of 3 to 6 miles, which corresponds to about 6–10 samples per county. In addition, at least one profile was obtained from every county. In contrast to the general surface samples the profiles were collected in layers of 10-inch thickness. In the present paper mainly the data for the 10-inch surface layer are reported. The route selected often followed new highways, which permitted easy measurements of the nature and depth of the carbonate accumulation zone. The borings were taken at least 50 yards (45.7 m.) away from the road. In undulating or rolling country the highest point of the ridges was selected for sampling purposes.

ZONE OF CARBONATES

Mature soil profiles of arid and semi-arid regions possesss a zone of carbonate accumulations which recently has received considerable attention because Marbut selected it as a major criterion for soil classification. Marbut's definition: "Pedocals are fully developed profiles in which lime carbonate is found on some horizon in the solum in higher percentage than in the parent geological

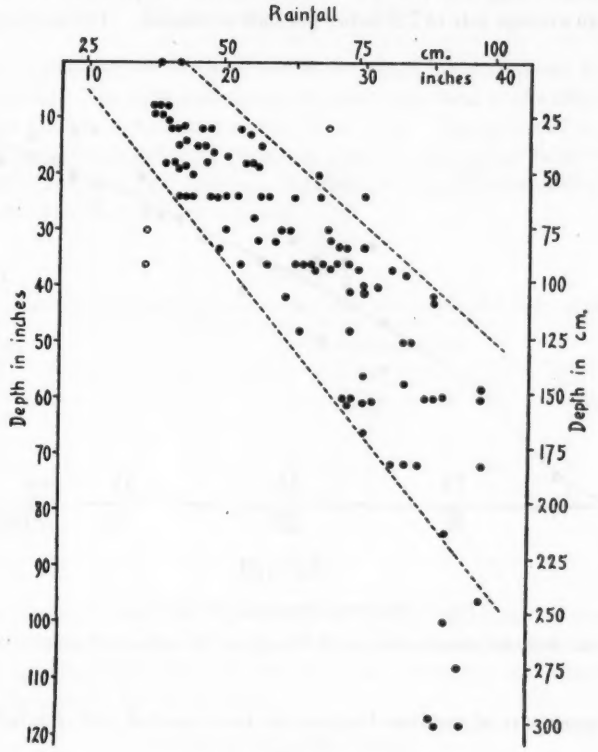

FIG. 2. DEPTH OF CARBONATE ZONE

The points indicate the position of the upper part of the accumulation zone. Observations made mainly along new highways.

formation beneath," is very clearly formulated from a logical point of view, but in the field it is frequently impossible to decide whether a lime carbonate horizon in Marbut's sense is present or not. This holds especially for soils derived from parent materials rich in carbonates.

During the entire trip the depth of the concretion zone was carefully recorded and, in case the accumulation zone was not clearly visible, the zone

nearest the surface which exhibited the strongest effervescence with dilute HCl was selected. In every case the data plotted in figure 2 refer to the depth of this upper boundary of the carbonate zone because in many soils the lime concretions are scattered throughout the entire lower part of the profile. Figure 2 very clearly shows *a linear band of considerable width which gradually descends into lower regions of the profile*, evidently as a result of leaching. The average descent begins at about 12 inches (30.5 cm.) of precipitation and proceeds at an average rate of 2.5 inches per inch of rainfall. The average depth

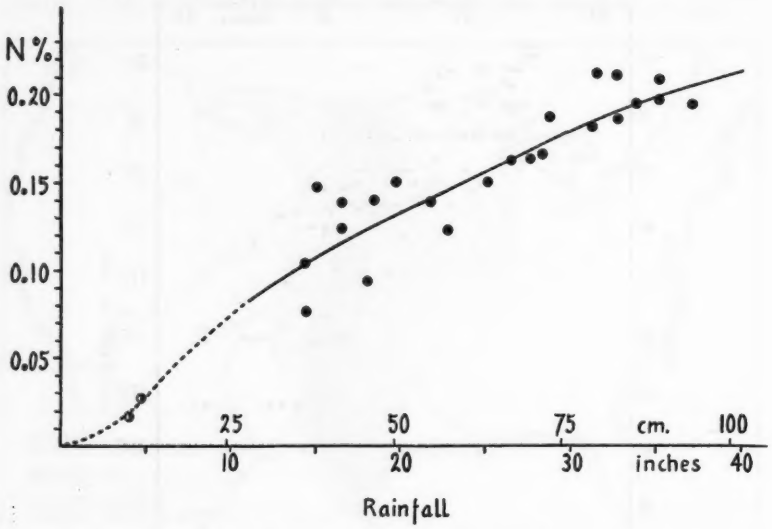

FIG. 3. NITROGEN-RAINFALL FUNCTION I

The points represent county averages (5–10 analyses) of surface soil samples 0–7 inches deep.

of this upper part of the lime horizon can be connected with rainfall (R) as follows:

$$\text{Depth} = 2.5(R-12)$$

The equation holds for R greater than 12 and smaller than 40. At lower rainfalls one would expect the curve to discontinue its linear character and approach $R = 0$.

Above 36 inches (91.4 cm.) of rainfall large lime concretions and even channels of secondary $CaCO_3$ are to be found at great depths in the highly weathered glacial till. These lime accumulations are considerably below the normal trend curve and do not necessarily represent typical lime horizons as defined by Marbut but may well be the result of ground water influences or even interglacial weathering.

NITROGEN

A nitrogen-rainfall curve along a similar isotherm has been previously published by one of the authors. The new surface samples analyzed in the present investigation confirm the earlier observations. *The nitrogen content of the soil (0–7 inches deep) as expressed by county averages varies logarithmically with increasing rainfall* as shown by the equation (fig. 3):

$$N = 0.320\,(1 - e^{-0.027R})$$

where N represents the nitrogen content of the soil in per cent and R the rainfall in inches. The constants agree very well[2] with those of the 1930 equation (3), if one takes into consideration that $H = 7.8\,R$. The scatter of the individual samples is considerable as evidenced from the correlation table 4. When a straight line relationship between nitrogen and rainfall is assumed a correlation coefficient of +0.68 is obtained.

TABLE 4

Classified single nitrogen analyses of surface soil samples, 0–7 inches depth

NITROGEN CONTENT OF SOIL	ANNUAL RAINFALL IN INCHES							
	0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40
per cent								
0.20–0.25						4	2	1
0.15–0.20				12	2	14	3	3
0.10–0.15			2	20	12	6	2	
0.05–0.10			8	2				
0.00–0.05	2							

It is of interest to compare the correlation table 4 with figure 4, which gives the individual analyses of the profile samples (first horizon, 0–10 inches depth). In this case a decidedly *linear relation exists between nitrogen and rainfall* which can be represented by the equation

$$N = 0.00655R - 0.0230$$

The degree of association between the two variables is very high as indicated by the correlation coefficient, which has a value of +0.946. Compared with table 4 the scatter of the individual profile points about the straight line is very much less. Two reasons may account for this behavior. First, it is possible that the profiles were more carefully selected than the numerous surface samples, and secondly, the greater depth (0–10 inches) of the former as compared with 0–7 inches of the latter may be responsible for the decline in variability. Obviously the smaller the depth of sampling the greater the fluctuations of the nitrogen content between the samples.

COLLOIDAL CLAY

Though most soil scientists agree that climate may influence certain soil properties, such as pH or organic matter, it is generally considered that the texture of a soil is primarily dependent on the nature of the parent material. The results of the present investigation, however, seem to indicate that the rôle of parent material is not always so exclusive as is usually considered. All surface horizons (0–10 inches) of the profile samples were subjected to mechanical analyses, and the colloidal clay (particles smaller than 2μ diameter) was

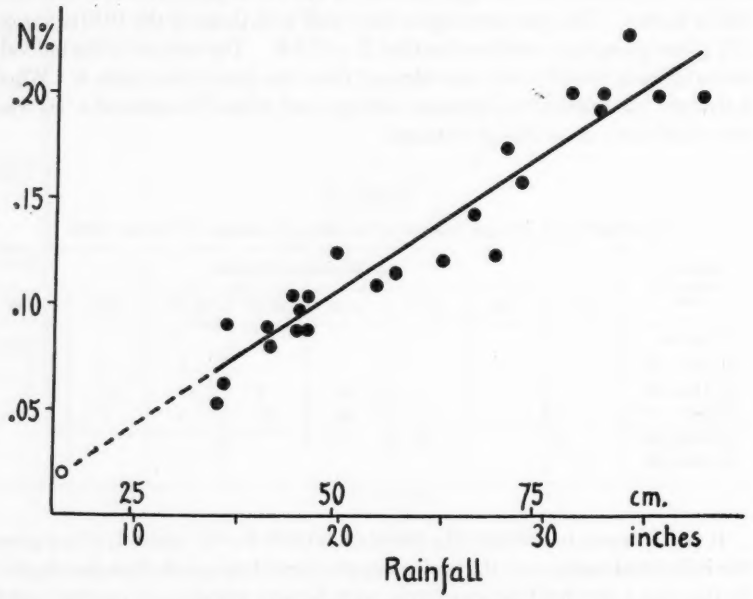

FIG. 4. NITROGEN-RAINFALL FUNCTION II

Every point refers to a single soil sample (0–10 inches surface layer) of the profile series

determined by the pipette method after oxidation of the organic matter with H_2O_2 and dispersion with sodium oxalate. From figure 5 it is clearly seen that the amount of colloidal clay in the surface soil increases regularly with increasing rainfall. The relation is very pronounced. It has a correlation coefficient of +0.820 and can be expressed by the linear equation

$$C = 0.914R + 1.33$$

where C represents the colloid content of the soil (0–10 inches) in per cent and R the annual rainfall in inches.

The observation that soil texture should be dependent on rainfall is surpris-

ing, and additional proof of such a relationship is greatly desirable. Fortunately, the numerous mechanical analyses published by the Bureau of Chemistry and Soils lend themselves to further studies.

From a similar temperature belt with a range from 52–56°F. (11.1–13.3°C.) all mechanical analyses from soil types covering more than 5 per cent of the area of a county were collected from data in the literature (1), and the clay content of the individual samples was plotted against the average rainfall of the county, as seen in figure 6. Again a decided correlation between texture

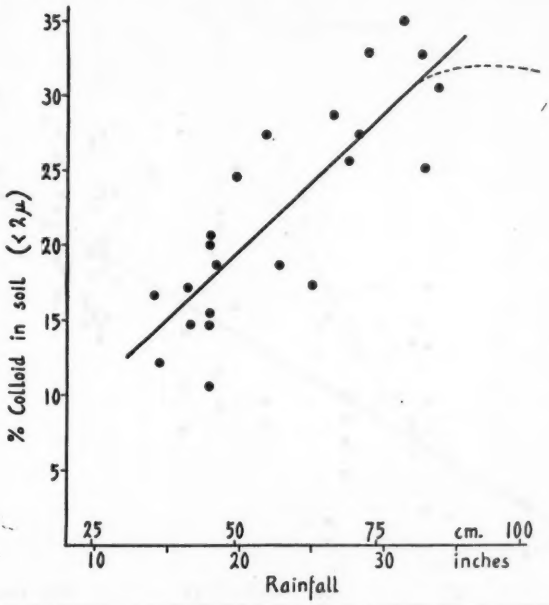

FIG. 5. AMOUNT OF INORGANIC COLLOID AS AFFECTED BY RAINFALL

(Individual samples of the profile series.) Data not included in this study indicate that under higher rainfall the colloid content of the surface soil begins to decrease as a result of eluviation.

and rainfall exists which, as measured by the correlation coefficient, has a value of +0.760. The equation fitted as usual by the method of least squares has the form

$$C_p = 0.567\ R + 4.52$$

where C_p represents the clay content of the soil in per cent and R the mean annual rainfall. *The clay curve agrees in principle with the colloid curve,* but it can not be directly compared on an absolute scale for the following reasons:

(*a*) The size of the particles determined is somewhat greater, namely "less than 5μ diameter."

(*b*) The clay determinations were carried out according to the old method of mechanical analysis using ammonia for dispersion. Compared with modern technique the amounts of clay obtained are in every case too low. However, the points in the graph are comparable among themselves.

(*c*) The clay data are not restricted to the surface layer 0–10 inches, but represent the average for the "surface soil" plus the "subsoil." The depth of sampling has not been consistent. In the majority of cases the surface soil refers to a depth of 0–8 or 0–10 inches and the subsoil extends from 8 or 10 to 36 or 40 inches. For this reason the average clay content of the "profile" was arbitrarily calculated according to the formula

$$\text{per cent clay} = \frac{S_1 + 3S_2}{4}$$

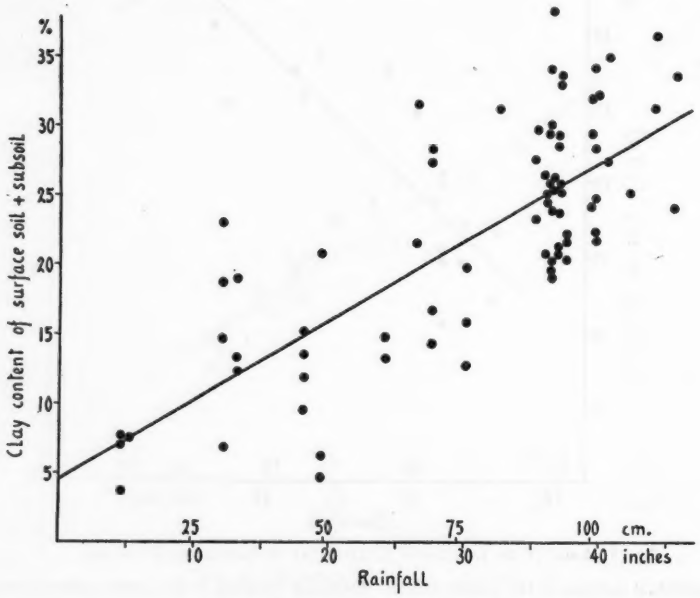

FIG. 6. CLAY-RAINFALL CORRELATION

Average clay content to a depth of 3 feet as calculated from data published by the Bureau of Chemistry and Soils.

where S_1 represents the clay content of the surface soil and S_2 that of the subsoil, both expressed in per cent.

(*d*) Parent material has not been kept constant. The soils originate not only from wind-blown material (including loess), but also from limestones, shales, sandstones, glacial till, and some tertiary lacustrine and alluvial deposits. These various types of rocks are rather evenly distributed over the entire area. The variable parent material probably is the major cause for the considerable deviations of the individual profiles from the average line.

The authors are of the opinion that the two clay equations represent not

merely a statistical association of two variables but a direct causal relationship in that the increasing moisture is considered to be responsible for the higher clay and colloid content of the soil as a result of intensified weathering.

SOIL ACIDITY

The pH determinations (quinhydrone electrode), of all surface samples have been plotted against rainfall in figure 7. The black points refer to the individual surface layers of the profile series (depth 0–10 inches), the black-white

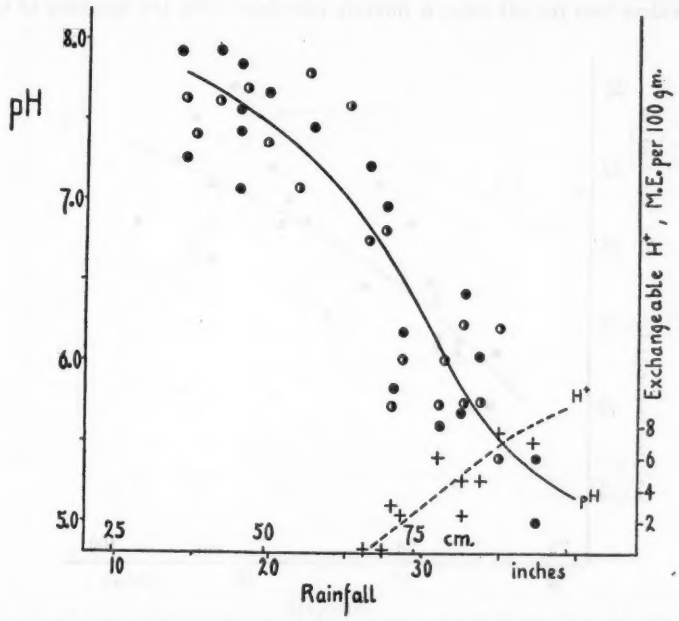

FIG. 7. SOIL ACIDITY RELATIONSHIPS. CHANGE IN pH AND EXCHANGEABLE H IONS WITH RAINFALL

Solid black points (pH) and crosses (H^+) represent the single values of the surface 0–10 inches of the profile series; black-white points refer to county averages of the 0–7 inch surface sample series.

circles represent the county averages of the numerous 0–7 inch surface samples. The resulting curve conclusively demonstrates the significance of climate as an important factor in soil formation. In the semi-arid region all soils show alkalinity, whereas acid reaction is characteristic for the humid districts. The pH extremes are linked up by a continuous series of decreasing pH values, with pH 7 (neutrality) appearing at a rainfall of about 25 inches (63.5 cm.). As a first approximation it can be said that every inch of rainfall reduces the average pH by one-tenth. The free-hand curve drawn resembles a clay titration curve of the system H-clay + $Ca(OH)_2$.

On the same graph (fig. 7) the number of exchangeable (adsorbed) H ions[3] of the profile surface layers are also shown and it is quite interesting to note that the appearance of exchange acidity coincides approximately with a soil reaction of pH 7. Both points lie in the eastern (humid) portion of the Chernozem belt. The presence of exchangeable H ions in the surface soil is typical for the semi-humid and humid regions, and the amounts are the greater the higher the rainfall.

When the saturation capacity curve in figure 8, is taken into consideration, it is evident that the pH value is directly correlated with the amounts of ex-

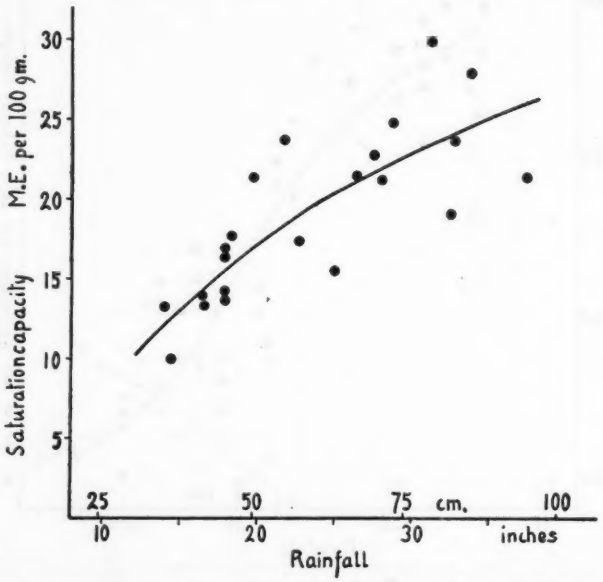

FIG. 8. SATURATION CAPACITIES OF THE 0–10 INCH SURFACE SAMPLES

Expressed by milliequivalents of total exchangeable cations per 100 gm. of soil

changeable H^+ and exchangeable bases, as far as the region below pH 7 is concerned. The descending branch of the pH curve can be fairly well described by the equation

$$\text{pH} = -0.07\,R + \log \frac{\text{exch. bases}}{\text{exch. } H^+} + 7.5, \text{ for } 26 < R < 40$$

where R represents annual rainfall and $\log \frac{\text{exch. bases}}{\text{exch. } H^+}$ refers to the base ratio which exists at any R.

[3] Determined by leaching with and subsequent electrometrical titration of originally neutral Barium acetate.

SATURATION CAPACITY

The saturation capacity or the total amount of exchangeable (adsorbed) cations including the hydrogen ions was determined by distillation with MgO of the NH_4 from the NH_4- saturated soil which had been prepared by leaching with neutral NH_4Cl and subsequent washing with alcohol. Figure 8 shows that with increasing rainfall the adsorption capacity of the soil for cations

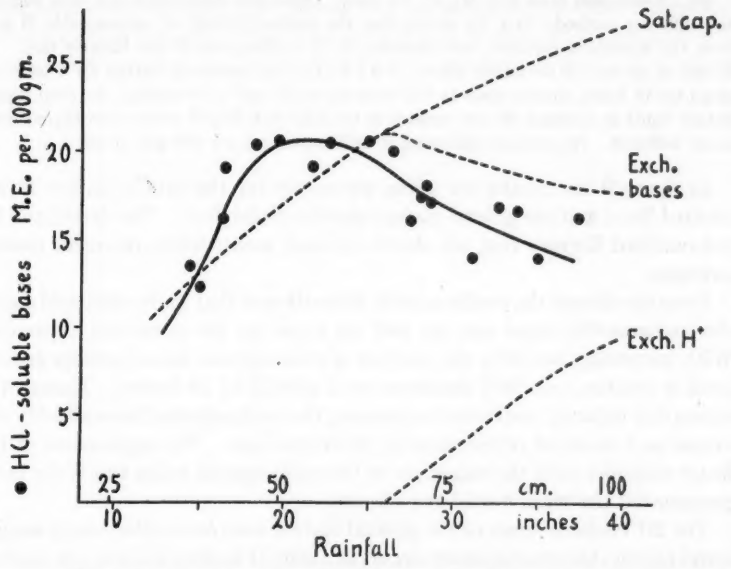

FIG. 9. RELATION BETWEEN EXCHANGEABLE CATIONS AND RAINFALL

The dotted lines refer to the 0–10 inch surface sample series, and the black points represent the total HCl-soluble bases of the 0–7 inch surface sample set assembled into county averages.

becomes gradually greater. The following equations satisfactorily describe the trend of the curve:

$$S = 32.40 \log R - 24.78 \qquad \text{for } 10<R<40$$
$$S = 14.06\, ln\, R - 24.78$$

where S represents the saturation capacity in milliequivalents per 100 gm. of soil, and R the rainfall. If R^1 is substituted for log R a straight line results which has a correlation coefficient of +0.815, indicating a pronounced correlation between rainfall and saturation capacity. The ascending trend of the curve in figure 8 is to be expected, since the amounts of colloidal clay and of the organic matter, which both are the seat of exchange adsorption, also become greater as rainfall increases (figs. 4 and 5).

EXCHANGEABLE CATIONS

The saturation capacity indicates how many exchangeable cations are contained in 100 gm. of soil. These were determined according to the following standard methods.

(*a*) *Exchangeable H ions:* Ten grams of soil was leached with normal neutralized Ba-acetate (pH 7) and the leachate was electrometrically titrated with $Ba(OH)_2$ to pH 7.

(*b*) *Exchangeable bases (Ca, Mg, K, Na ions):* These were determined in a lump sum by two different methods: first, by subtracting the milliequivalents of exchangeable H ions from the saturation capacity, and secondly, by a modification of the Kappen test. To 20 gm. of air-dry soil are added 100 cc. of 0.1 *N* HCl, the mixture is shaken for 1 hour, let stand for 15 hours, shaken again (a few times by hand) and after settling, the clear supernatant liquid is siphoned off and titrated in the cold with NaOH using brom thymol blue as an indicator. All data are expressed in milliequivalents per 100 gm. of soil.

In figure 9 the results are given separately for the profile surface layers (dotted lines) and the general surface samples (solid line). The latter, run by the modified Kappen test, are shown as black points which represent county averages.

From the data of the profile series it is clearly seen that in the semi-arid region the exchangeable bases are low and are equal to the saturation capacities. With increasing humidity the number of exchangeable bases becomes greater until it reaches a decided maximum at a rainfall of 26 inches. Though the saturation capacity continues to increase, the exchangeable bases steadily decrease as a result of replacement by hydrogen ions. The appearance of the latter coincides with the maximum of the exchangeable bases and is the more pronounced the more humid the climate.

The HCl-soluble bases of the general surface samples exhibit a very similar trend except that the maximum occurs at about 21 inches (52.1 cm.) of rainfall. The cause of this discrepancy probably lies in the analytical method employed and in the difference in depth of sampling.

DISCUSSION OF THE NATURE OF THE FUNCTIONS OBTAINED

The curves presented strongly suggest that soil formation is not of unconquerable complexity, and in addition they demonstrate that it is possible to isolate a major soil forming factor and describe its effect by numerical equations.

The *straight line relations* are very simple mathematical functions yet they are somewhat difficult to comprehend because they ascertain that every inch of rainfall is equally effective in the formation of a given soil property (figs. 2, 4, 5, 6). Furthermore, they lead occasionally to negative values for low moisture figures. Since it is to be doubted that rainfall effectiveness should be merely additive, one is led to conclude that the linear relationships are either coincidental as resultants of several functions, or—what is highly probable—they are restricted to relatively small areas with not too wide ranges of rainfall.

The *logarithmic curves* are more significant. They reveal that 1 inch of rain-

fall is less effective in humid regions than in arid ones. In view of the runoff data in table 1, such a behavior seems quite plausible because runoff becomes more than proportionally greater as rainfall increases. The tendency of the logarithmic curves to reach a maximum suggests that under high rainfall an additional inch of rain has little effect on soil formation.

Sigmoid curves. Though the logarithmic curves appear reasonable in describing the rate of soil formation under abundant rainfall, they can not be considered truly representative for soil conditions in arid regions. According to the slopes of the logarithmic curves the first inch of rainfall (or its equivalent in any other moisture value) should be the most effective one, a conclusion

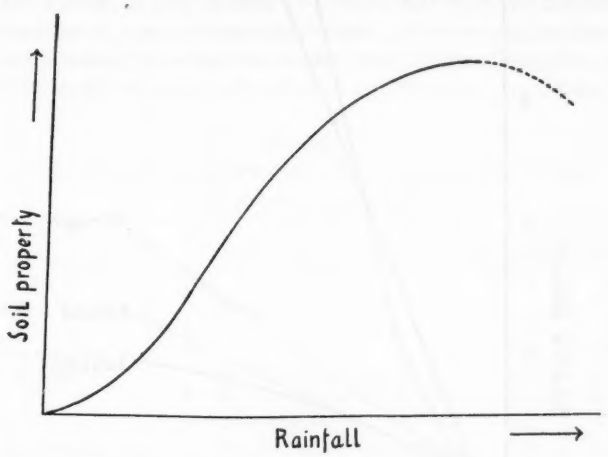

FIG. 10. GENERALIZED SIGMOID CURVE SHOWING AN INFLECTION POINT IN THE SEMI-ARID REGION AND A MAXIMUM UNDER HIGH RAINFALL

which disregards the appreciable moisture holding capacity of any parent material and soil. A sigmoid curve of the general type

$$y = \frac{a}{1 + be^{F(x)}}$$

as shown in figure 10 would be more satisfactory and would embrace a considerable number of soil property-rainfall functions. Such curves may also contain maxima, as have been found for the exchangeable bases.

INTENSITY OF SOIL FORMATION

The magnitude of the differential coefficients (slopes) of the curves permits a quantitative insight into problems of intensity of soil formation.

Rainfall effectiveness. Generally speaking the effectiveness of one inch of rainfall (R) is highest at the point where the value of $f'(R)$[4] reaches a maximum.

[4] $f'(R)$ represents the derivative of the function $f(R)$.

On the basis of sigmoid curves such as represented in figures 3 and 10, that particular point (inflection point) appears to occur in the semi-arid region. In other words, it is in dry regions with steppe-like soils that 1 inch of rainfall is most powerful in its effect on soil formation processes, such as nitrogen accumulation, development of saturation capacities, and formation of colloids. In regard to pH, however, the critical point lies in the semi-humid region.

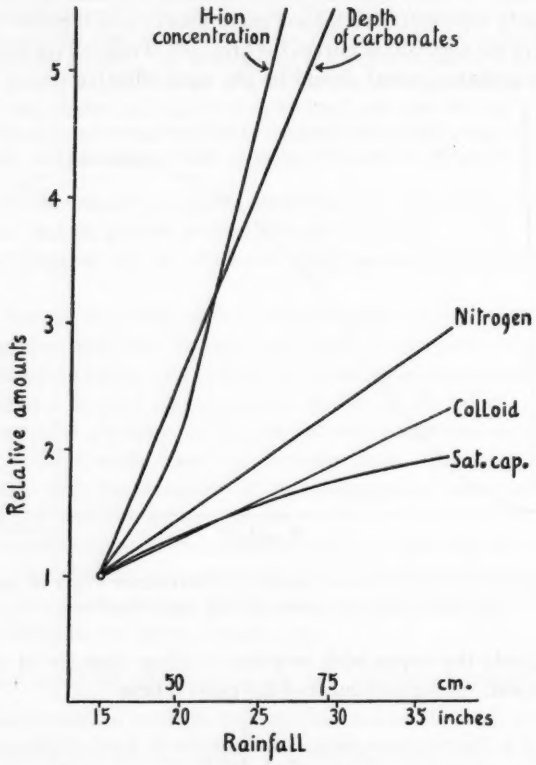

FIG. 11. RELATIVE SOIL PROPERTY-RAINFALL CURVES DEMONSTRATING THAT VARIOUS SOIL CHARACTERISTICS EXHIBIT DIFFERENT RATES OF FORMATION

Rate of soil formation, $f'(R)$. The influence of rainfall upon soil formation is not the same for all constituents involved in the process, and furthermore, it often varies with the amount of rainfall itself. This contention is well illustrated in figure 11, which shows the formation of certain soil characteristics on a comparable basis. These relative curves were obtained by arbitrarily putting the value of the soil property at $R = 15$ equal to 1. Three groups of curves can clearly be distinguished:

High rate of formation = H-ion concentration, depth of carbonate horizon.
Medium rate of formation = nitrogen (and organic matter).
Low rate of formation = colloidal clay, saturation capacity.

The magnitudes of these various rates for the rainfall interval 15–35 inches are listed in table 5, which also contains the percentage increase of the soil properties for the same moisture interval. *Evidently the H-ion concentration (negative antilog of pH) and the depth of the carbonate horizon react most sensitively toward rainfall. Next comes nitrogen and finally clay and saturation capacity.* Nitrogen increases 1.75 times, or 75 per cent, faster than colloidal clay. The crossing of the carbonate over the H-ion curve is particularly instructive. Under low rainfall, H ions increase at a slower rate than the carbonates are being translocated, whereas under high rainfall, the reverse takes place. Evidently carbonates in the soil act as a buffer toward increase in acidity, and it is not until the buffer is sufficiently removed that H ions can accumulate at full

TABLE 5

Relative intensities of soil formation for the rainfall interval 15–35 inches

(Surface layers of profiles)

SOIL PROPERTY	FUNCTION	INCREASE OF SOIL PROPERTY BETWEEN 15–35 IN.	AVERAGE RELATIVE RATE OF INCREASE (SLOPE) $f'(R)$
		per cent	
H-ion concentration		18,700	$1600 \cdot 10^{-2}$
Depth of carbonates	$D = 2.5\,(R - 12)$	667	$33.3 \cdot 10^{-2}$
Nitrogen	$N = 0.00655R - 0.023$	175	$8.7 \cdot 10^{-2}$
Colloidal clay	$C = 0.914R + 1.33$	122	$6.1 \cdot 10^{-2}$
Saturation capacity	$S = 14.06\,ln\,R - 24.78$	90	$5.0 \cdot 10^{-2}$

speed. This conclusion based on numerical functions obtained in the field agrees with what one would expect on the basis of chemical laws.

LOCATION OF BOUNDARY BETWEEN ARID AND HUMID CLIMATES

Geographers and climatologists have made considerable efforts to locate the boundary between arid and humid regions. Their attempts rest mainly on comparisons of rainfall and evaporation or discharge of rivers. For instance, Penck defines the boundary as the point at which evaporation is equal to precipitation. Often the hundredth meridian, which corresponds to a rainfall of 20 inches (50.8 cm.) for the region studied by the authors, has been taken as an approximate boundary line. The data obtained in this investigation throw some interesting light on the problem as viewed from the standpoint of soil characteristics as an index of the division line. In certain respects the climatic boundary should be related to Marbut's major soil boundary which divides all mature soils into pedocals and pedalfers on the basis of the presence or absence of a lime horizon. Marbut tentatively puts the boundary into Clay County,

Kansas, which corresponds to an annual rainfall of 27–28 inches (70 cm.). Since figure 2 discloses that in the region selected by Marbut the carbonate layers descend gradually with increasing rainfall without abrupt breaks, it is not known why the particular lime-depth 20–60 inches has been selected as the critical one. Mathematically speaking the lime horizon-rainfall relation is a monotone continuous function and as such is not well suited for classification purposes, unless it be connected with at least one other function, say the depth of the solum for example.

Of special interest are the exchangeable H ions and total exchangeable bases. At 26 inches the soils begin to contain measureable amounts of exchangeable H ions, and one might—in agreement with Gedroiz (2)—characterize the two regions by the absence or presence of exchangeable H ions. The total exchangeable bases also are significant because their rainfall function exhibits a maximum. One might set the arid-humid boundary at that locality where the

TABLE 6

Criteria and locations of the arid-humid boundary

CRITERIA	LOCATION IN KANSAS (COUNTY)	AVERAGE ANNUAL RAINFALL		ANNUAL N.S.Q.	ANNUAL TEMPERATURE
		inches	*cm.*		°C.
100th meridian	Graham	20	50.8	156	11
Marbut lime horizon	Clay	27	68.6	210	11
Neutral reaction (pH = 7)	Cloud	25	63.5	195	11
Appearance of exch. H+	Cloud	26	66.0	202	11
Max. of exch. bases	Cloud	26	66.0	202	11
Meyers value in Central Europe (discharge of rivers)		16.5	42	207	8–10

average exchangeable bases are highest, or $f'(R) = 0$. For the pedocals $f'(R)$ would be positive, for the pedalfers it would be negative. In other words, the two major groups would be separated on the basis of the plus or minus sign of the differential coefficient. Naturally the exact geographical position of the boundary depends on the method of soil sampling and analysis, but this does not affect the definition of the criteria previously formulated (compare table 6).

SUMMARY

Along the 11°C. isotherm numerous soil samples were collected from fairly uniform parent material consisting primarily of wind-blown deposits. The variations in annual rainfall cover a range of 14–38 inches (35.6–96.5 cm.).

The zone of carbonate accumulation was found to decrease at a rate of 2.5 inches for each inch of rainfall.

Nitrogen increases continuously with increasing rainfall. The functions obtained confirm those previously published.

Under high rainfall the formation of colloidal clay is intensified. It increases at a rate of about 1 per cent per inch of rainfall.

Soil acidity changes regularly from pH 7.8 in the semi-arid region to pH 5.2 in the semi-humid one. Neutral reaction is reached at about 25 inches of rainfall (N.S.Q. = 195). Exchangeable H ions appear at 26 inches of rainfall (N.S.Q. = 202), and become very numerous in the semi-humid region.

The saturation capacity has a value of 12 m.e. per 100 gm. of soil in the semi-arid region and increases logarithmically to 27 in the semi-humid areas.

The exchangeable bases exhibit a maximum (21 m.e.) at a rainfall of 26 inches (N.S.Q. = 202).

On the basis of differential coefficients the relative rate of formation is highest for the H-ion concentration and removal of carbonates. It is lowest for the clay formation and development of saturation capacity. Nitrogen and organic matter occupy an intermediate position.

The boundary between arid and humid climates as based on the soil properties investigated appears to correspond to a rainfall of 25–26 inches (N.S.Q. 200) for the 11°C. isotherm.

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SUBDIVISION OF THE UPPER PENINSULA EXPERIMENTAL FOREST[1] ON THE BASIS OF SOILS AND VEGETATION

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Forest tracts are usually classified for purposes of forest management on the basis of vegetative cover type. Frequently, such a classification when considered alone is unsatisfactory, since cover type may be, and often is, a temporary condition and thus does not give a true expression of forest productivity or indicate the form of management that should be practiced. There is a need for something more basic and fundamental.

It was believed that an investigation of the genetic features of the soil would throw much light on the question. Accordingly, a study was made during 1929 of the soils and vegetation of the Upper Peninsula Experimental Forest, located at Dukes, Michigan. At this time 150 soil profiles were investigated, and the composition and growth of the forest and herbaceous vegetation were observed on a number of sample plots. From the information obtained, the area was subdivided into ecologically uniform compartments in order to establish a natural basis for all silvicultural management such as cutting, thinning, and planting. The methods and results of the study are summarized briefly in this paper.

GENERAL CHARACTERISTICS OF THE AREA

The experimental tract comprises the north half of section 35, and the south half of section 25, in Township 46 North, Range 23 West.

The climate of the area is typical of a podzol region (6). The mean annual temperature is 39°F. The highest temperature is about 96°F.; the lowest, minus 40°F. The mean annual precipitation is 33 inches. The mean temperature for the growing season (June 1 to September 30) is approximately 59°F. The precipitation for the same period is 14 inches. Approximately half of the days during the growing season are wholly or partially cloudy. The general altitude of the tract is about 400 feet above the level of Lake Superior. The topography is of a gently rolling character, and with local differences in elevation not exceeding 50 feet. The country rock of the area is Upper Cambrian sandstone. For the most part, this is covered with an unassorted drift derived from sandstone and crystalline rocks. The depth of the drift sheet is

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in places as shallow as 2 feet, but is ordinarily deeper. In a few localities, between the sandstone and the till, is found a layer of highly calcareous lacustrine clay. Some of the morainic depressions are filled with the remains of aquatic and swamp vegetation. The narrow bands along the creeks include recent post-glacial deposits of mineral and organic matter. The surface of the area is drained by the headwaters of Whitefish River and several creeks. The internal drainage of the soil is often poor as a result of the influence of near-surface sandstone, or colloidal glacial till.

Twelve tree species—six deciduous and six coniferous—are found in the virgin forest of the Dukes' area. They are: sugar maple (*Acer saccharum*, Marshall), yellow birch (*Betula lutea*, Michaux), basswood (*Tilia glabra*, Ventenat), American elm (*Ulmus americana*, L.), red maple (*Acer rubrum*, L.), black ash (*Fraxinus nigra*, Marshall), eastern hemlock (*Tsuga canadensis*, L., Carriere), white spruce (*Picea glauca*, Moench, Voss), balsam fir (*Abies balsamea*, L. Miller), tamarack (*Larix laricina*, DuRoi, Koch), black spruce (*Picea mariana*, Miller, Briton), and northern white cedar (*Thuya occidentalis*, L.) Among the more important woody plants are: leatherwood (*Dirca palustris*), ground hemlock (*Taxus canadensis*), tag alder (*Alnus rhombifolia*, Nuttal), and dogwood (*Cornus florida*).

METHOD OF STUDYING AND SUBDIVIDING THE FOREST

In a preliminary survey, a rough contour map was prepared, and the natural elements of topography, such as hill tops, elevated shelves or flats, basins, and valleys, were blocked out. After the area had been subdivided upon the basis of its topographical features, soil profiles were dug. The thickness of each layer, its physical and chemical character, the depth to which roots penetrated, conditions of moisture, and the depth at which the water table occurred were recorded both descriptively and graphically (fig. 1). In addition to this a complete set of soil samples and 10 monoliths of representative soil profiles were taken and carefully investigated.

Different layers or horizons of the profile were designated according to Glinka (1), as follows: A_0—forest litter; A_1—infiltrated or humic layer; A_2—eluvial, leached, or podzolic horizon; B—illuvial or accumulative horizon; C—parent material of the soil (rock or weathered substratum); G—deoxidized or gley horizon, formed by the action of ground water. The forest floor has been classified after Mueller (4) and Hesselman (2) into two major types: *mull* and *raw humus*. The standard United States textural classification, viz., sand, sandy loam, fine sandy loam, silt loam, and clay, has been used in the description of the soil profiles (5).

With a few exceptions, the parent soil material of the entire area is stony and gravelly fine sandy loam. In spite of this textural homogeneity of the soil, the forest vegetation shows essential differences in its composition and growth. It was found that these differences have resulted largely from the so-called genetic, or clima-zonal features of the soil, such as leaching, development of

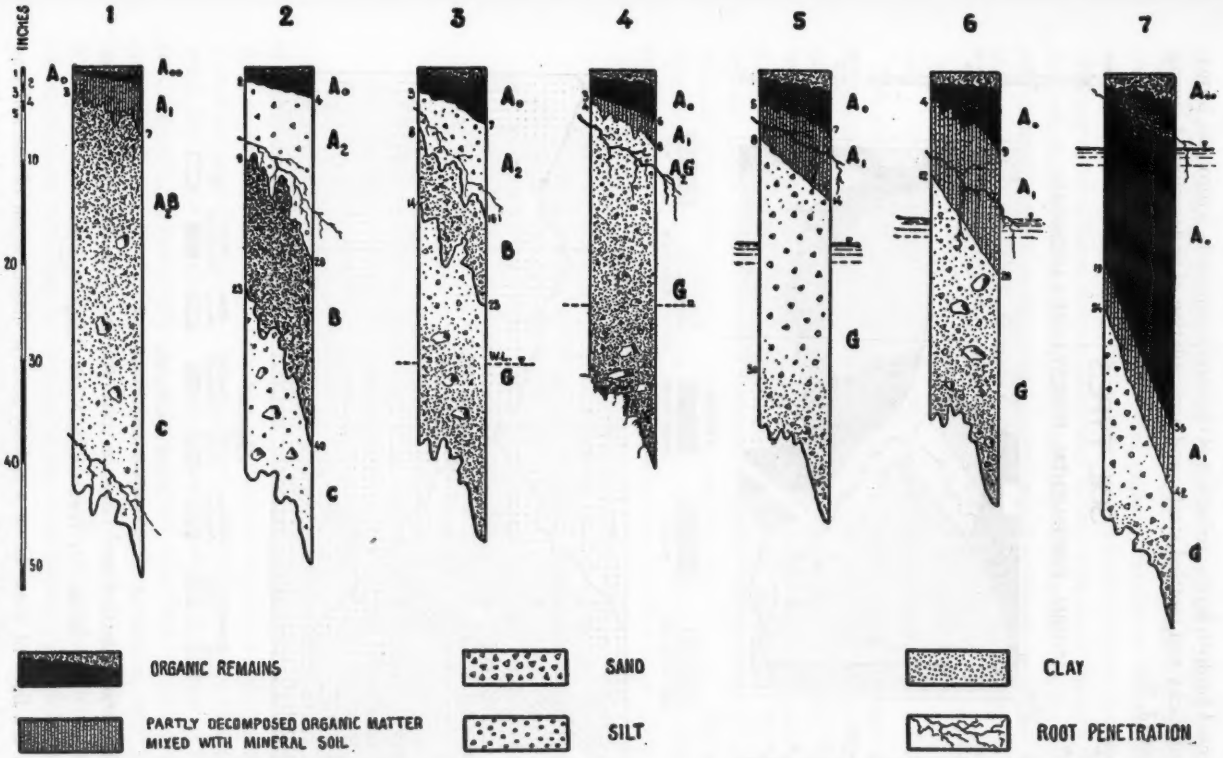

FIG. 1. SCHEMATIC REPRESENTATION OF TYPICAL SOIL PROFILES, SHOWING THE MINIMUM AND MAXIMUM DEPTHS OF THE HORIZONS

1. Slightly podzolized loam; 2, loamy podzol with hardpan; 3, swampy podzol with hardpan and gley, formed on glacial till; 4, swampy podzol with gley, formed on sandstone; 5, formed on alluvial sand; 6, muck, formed on glacial till; 7, woody peat.

cemented hardpan layers, reduction of chemical compounds, hydrolysis, formation of sticky and mottled strata, and accumulation of undecomposed organic matter (3, 9).

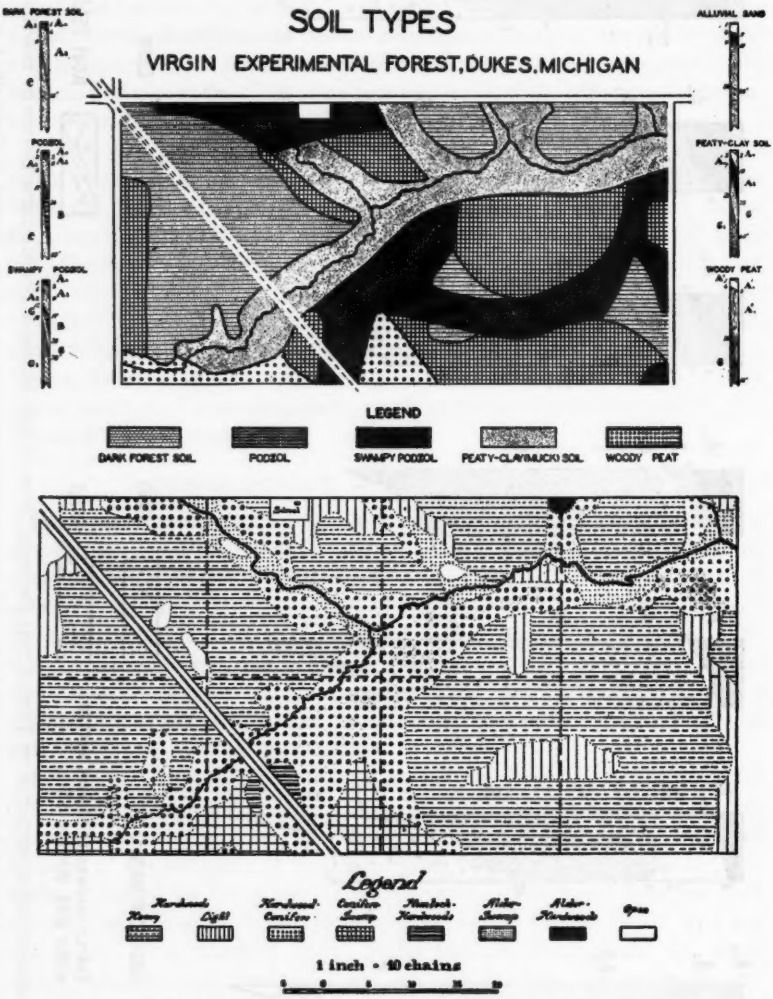

FIG. 2. (*a*) SOILS AND (*b*) FOREST COVER OF VIRGIN PORTION OF THE EXPERIMENTAL FOREST
Section 35, Township 46, North, Range 23, West

In the light of these facts, a strictly genetic classification of the soil was adopted for mapping the soils, and five soil types were recognized, as follows: (*a*) slightly leached, or slightly podzolized loam, or "dark forest soil"; (*b*)

strongly leached and cemented soil, or "podzol"; (*c*) poorly drained, leached and mottled soil, or "swampy podzol"; (*d*) half organic, half mineral soil, in areas subject to overflow, or "muck"; (*e*) organic deposits, or "woody peat."

On the basis of these soil types, the area was subdivided into compartments. The boundaries of these compartments were laid out with a compass and chain, the trees along them were blazed, and a soil map was prepared (fig. 2a). Independently of the soil work, a forest cover map (fig. 2b) was made by E. L. Mowat, who was in charge of the Upper Peninsula Forest during 1929.

SOILS, FOREST COVER, AND HERBACEOUS VEGETATION

Slightly podzolized soils (dark forest loam, mull loam)

The slightly podzolized type of soils occupies the higher, well-drained areas such as elevated benches and slopes. The soil is of a fine sandy loam texture, nearly uniform throughout the profile, and is characterized by a dark grayish brown color. The top layer shows a complete mineralization of organic remains, and an abundance of readily available mineral plant food. The mineral soil has a loose, somewhat crummy structure, adequate water-holding capacity, and perfect aeration. Acidity varies fron pH 5.5 to 6.5. The roots penetrate to a depth of 4 to 5 feet, or more. Ground water seldom occurs at a depth of less than 10 feet. The description of a typical profile follows (plate 1a):

A_0' Thickness 0.5 to 1.0 inch. Undecomposed maple leaf litter.

A_0'' Thickness about 1.0 inch. Half decomposed mull mulch of a dark brown color and granular structure. Interwoven with roots. Slightly acid or nearly neutral. Has the odor of good garden soil.

A_1 Thickness 1.0 to 2.0 inches. Dark gray humic layer of a loamy texture, infiltrated with the products of mulch decomposition. Slightly acid.

A_2 Not present, or appears as small grayish spots in the upper portion of the profile.

B Not present.

C Thickness about 35.0 inches. Dark brownish gray fine sandy loam, mixed with gravel and some larger fragments of sandstone and granitic rocks. Moderately acid in reaction (pH 5.5). At a depth of 3 to 4 feet it grades into an unassorted glacial till underlain by a somewhat fractured plane of sandstone.

Slightly podzolized soils are associated with a pure hardwood type consisting of sugar maple, basswood, American elm, and some yellow birch. The understory of stands consists of a luxuriant reproduction of sugar maple, partially of seed and partially of sprout origin (plate 2a). With the exception of leatherwood, few shrubs are present. Ground cover vegetation is limited to Solomon's seal (*Polygonatum biflorum*), false Solomon's seal (*Smilacina racemosa*), twisted-stalk (*Streptopus roseus*), bellwort (*Uvularia perfoliata*), and some species of Viola. The scarcity both in species and number of herbaceous flora is one of the striking features in these virgin hardwood stands. Floristically, therefore, these areas may be classified as the *Acer-Nudum* type (plate 2a).

Podzol soils (strongly leached and cemented loam)

The podzol soil occurs on knolls, ridges, and elevated flats. The texture is often slightly sandier than that of the mull loam just described. The organic

matter is accumulated as raw humus. Relatively strong organic acids, formed as by-products of decomposition, have caused the leaching of calcium, magnesium, potassium, iron, and aluminum from the upper soil layers. In the lower part of the profile, the iron and aluminum compounds come in contact with the bases of the parent material and are precipitated. As a result of this process, the soil shows two characteristic layers: the ash-like, purely silicious, podzolic layer, and the rusty, reddish brown, ortsand or ortstein layer. Because of the translocation of chemical compounds, a considerable portion of the mineral plant foods are in a condition unavailable to plants. The reaction of the soil is extremely acid—often as low as pH 4.0, and seldom higher than pH 5.0. The soil is compacted, structureless, and as a rule cemented in the lower part of the profile. Because of the highly colloidal nature of the subsoil, the water-holding capacity is high, and aeration is not adequate for the best tree growth. Tree roots are concentrated in the upper portion of the profile. The following description is typical of the podzol soil of the Dukes' area (plate 2b):

A_0 Thickness 3 to 4 inches. Slightly decomposed organic layer of a dark brown color. Penetrated by the mycelium of fungi. Has a disagreeable sour odor, and a strongly acid reaction (pH 4.0 to 4.5). Line of demarkation between A_0 and A_2 is sharply defined.

A_1 Not present.

A_2 Thickness 9 to 12 inches. Light gray, ash-like, structureless, leached fine sandy loam. Strongly acid (pH 3.8 to 4.0). This horizon often has irregular, tongue-like lower limits.

B_1 Thickness 7 to 12 inches. Slightly cemented fine sandy loam of a coffee-brown, somewhat reddish color.

B_2 Thickness 15 to 20 inches. Rock-like, firmly cemented hardpan layer (Ortstein) of a dark coffee-brown color. Strongly acid. Free of tree roots.

C Unassorted, gravelly till.

All podzol profiles studied on the experimental area are fully developed and nearly always have a firmly cemented hardpan layer.

The forest cover on podzols is made up of hemlock, yellow birch, and somewhat inferior sugar maple. Occasionally balsam fir is present in the understory. Ground hemlock is one of the most characteristic woody plants. The herbaceous association is of a saprophilous nature, and includes the following species: Clintonia (*Clintonia borealis*), dwarf Solomon's seal (*Maianthemum canadense*, Desf.), gold thread (*Coptis trifolia*, L.), bunchberry (*Cornus canadensis*, L.), star flower (*Trientalis americana*, Purs.), wood sorrel (*Oxalis acetosella*, L.), partridge berry (*Mitchella repens*), and a number of species of club mosses (*Lycopodium lucidulum*, *Lycopodium annotinum*, *Lycopodium obscurum*, etc.). Clintonia and club mosses seem to be the best indicators of a pronounced soil degradation, and for this reason this site may be classified as the *Clintonia-Lycopodium* type (plate 2b).

Swampy podzol (mottled loam, gley soil)

The swampy podzol soil type is confined to the lower, swamp-border slopes, valleys, and basins, in areas characterized by a high water table. Because of

the surface deposition of eroded material from the upper slopes, the texture of swampy podzol is somewhat heavier than that of upland soils. The decomposition of organic remains is very slow, and some peaty material is formed. The soil is leached, compacted, and sometimes cemented. The illuvial layer grades into sticky gley horizons with reddish brown or green mottlings of ferric and ferrous iron oxides. Because of the impervious nature of the gley layer, the ground water may be within 4 to 5 feet of the surface during most of the growing season. Since the soil is excessively saturated, aeration is at a minimum. The top-soil is strongly acid, but the deeper subsoil is sometimes rendered neutral by the hydrolytic action of the water. The mineral plant food is largely unavailable to trees. Root concentration is limited to the upper soil layers. The characteristic features of a typical profile are:

A_0 Thickness 4 to 5 inches. Half decomposed dark brown or blackish brown organic accumulation. Somewhat peaty. Strongly acid.

A_1 Thickness 2 to 4 inches. Dark gray to grayish black humic loam.

A_2 Thickness 4 to 8 inches. Light yellowish gray, leached and strongly acid loam, or fine sandy loam with some fine featherings of humus compounds.

B Thickness 10 to 16 inches. Reddish brown, somewhat cemented and compacted fine sandy loam with intensively colored flakes and concretions. Acid in reaction.

G Thickness 12 inches. Yellowish gray sandy loam with an irregular admixture of clay particles. Mottled reddish brown. Sticky and plastic. Some gravel, boulders, and fragments of sandstone are present. Slightly acid. Permanently wet in the lower part of the profile.

C Sandstone bedrock.

Occurring as a transitional form between well-drained upland areas and swamps, swampy podzol shows a number of morphological variations, dependent upon the development of podzolic, ortstein, and gley layers (plate 1, c and d). All of these variations, however, have a minor ecological significance, because of the pronounced essential features: excessive moisture, insufficient aeration, and unavailability of plant nutrients.

The forest cover on swampy podzol is made up of very inferior sugar maple, red maple, mountain maple (*Acer spicatum*, LaMarck), yellow birch, American elm, black ash, and some balsam fir, white spruce, and other conifers. The percentage of these species varies considerably. Growth is poor, especially in the proximity of swamps. Shrubs and herbaceous plants include the members of both upland and swamp flora. In many places the ferns replace other species so completely that a *fern* type can be recognized (plate 2c).

Muck (peaty-clay soil, Sapropel soil)

Muck soils are confined to the low, poorly drained areas subject to overflow. As a rule, muck areas are broken by island-like formations of swampy podzol or woody peat, resulting from small changes in relief and drainage. The top-soil of muck is formed partially by the decomposition of plants *in situ*, and partially by the deposition of both mineral (silt and clay) and organic matter during inundations. The amount of inorganic particles in the upper, so-called

"Sapropel" (7) layer of soil varies from 30 to 70 per cent, and the total thickness of the layer varies from several inches to 2 or 3 feet. The substratum of muck is either unassorted till or alluvial sand (plate 1 e and f). In one case muck was found resting upon calcareous lacustrine clay which, in a dry state, reacted violently with hydrochloric acid. Muck contains a large quantity of both nitrogen and basic material (mainly calcium), and is potentially the richest of all organic soils in the region. However, because of the excessive saturation of the soil and insufficient aeration, the mineral plant food of muck is largely unavailable to the trees. A typical muck profile shows the following characteristics (plate 1e):

A_0 Thickness 3 to 5 inches. Half decomposed, dark brown organic matter of somewhat granular structure.

A_1 Thickness 15 to 18 inches. Plastic and moist brownish gray, steel or bluish gray mixture of organic, peat-like material and clay. Slightly acid (pH 6.0).

G Thickness 20 inches. Wet, compacted gravelly sandy loam of yellowish gray color with sharply pronounced brownish and greenish mottlings and agglutinations. Neutral or slightly alkaline in reaction (pH 7.0 to 7.5).

The typical forest cover on muck is comprised of water-loving hardwoods and conifers. These include red maple, black ash, yellow birch, American elm, balsam fir, spruces, tamarack, and some northern cedar. Sugar maple occurs along the upland border. Approximately 50 per cent of the trees on this type are deciduous and 50 per cent coniferous species. Tag alder (*Alnus rhombifolia*), willow (*Salix spp.*), gooseberry (*Ribes spp.*), currant (*Ribes americanum*), dogwood (*Cornus florida*), hazelnut (*Corylus colurna*), and dwarf rubus (*Rubus triflorus*) are the most common woody plants. In places, the hardwood-coniferous type is replaced by a dense growth of tag alder. The herbaceous cover is characterized by wood nettle (*Urtica Lyallii*), bed straw (*Gallium asprellum*), horse-tail (*Equisetum*), tear thumb (*Persecara spp.*), arrow head (*Sagittaria spp.*), geranium (*Pelargonium*), ferns, some mosses, and numerous grasses and sedges. Floristically this site may be classified as *Urtica-Gallium* type.

Woody peat

Woody peat is confined to the areas with somewhat stagnant water. The upper portion of the profile consists of an accumulation of slightly decomposed remains of herbaceous and tree vegetation, particularly the wood of white cedar. The underlying mineral substratum is permanently saturated with water and usually shows a typical mottling of the gley layers. The organic layers are strongly acid. The mineral subsoil is often alkaline, because of the presence of carbonates or a high saturation of base exchange material. For the most part the roots of trees and other vegetation are confined to the upper 1-foot layer. A typical woody peat profile follows (plate 1g):

A_0' Thickness 3 inches. Half decomposed leaves, needles, mosses, and roots of trees and herbaceous vegetation. Strongly acid.

A_0'' Thickness about 36 inches. Little decomposed remains of swamp trees, mainly white cedar, colored brown or black. Many fragments of wood retained their identity. These wood fragments often are slimy to the touch and have a strong, disagreeable smell of hydrogen sulfide. Strongly acid.

A_1 Thickness 3 to 8 inches. Plastic, wet, peaty-clay material of a black color, formed partly by previous decomposition of organic matter, and partly by the dispersion of mineral and organic exchange material through the agency of water.

G Wet sand with some gravel and varying amounts of clay. Green mottlings or agglutinations are common. Alkaline.

The forest cover on woody peat is chiefly northern white cedar, although a little balsam fir, white and black spruce, tamarack, black ash, and red maple also commonly occur. Most of the tamarack has been killed by the larch sawfly (*Nematus Ericksonii*), and only new growths of this tree are found at present. Some water-loving shrubs occur in limited numbers. Tag alder is found along the borders of most woody peat swamps. The principal species of ground-cover vegetation are wood sorrel (*Oxalis acetosella*), dwarf Solomon's seal (*Maianthemum canadense*), gold thread (*Coptis trifolia*), clintonia (*Clintonia borealis*), and dwarf rubus (*Rubus spp.*). Of slightly less importance are bunchberry (*Cornus canadensis*), creeping snowberry (*Chiogenes hispidula*), twinflower (*Borealis americana*), bishop's cap (*Mitella nuda*), star flower (*Trientalis americana*), some ferns, and *Polytrichum*, *Sphagnum*, *Mnium*, and other genera of mosses. Floristically this site may be classified as *Oxalis* type (plate 2d).

CORRELATION OF SOILS WITH FOREST GROWTH

Observations made in virgin stands on the Dukes area and nearby indicate that sugar maple attains somewhat greater height on slightly podzolized soil than on podzol. The height growth of this species on both of these soils is considerably greater than on swampy podzol and muck. The total number of trees per acre, the average basal area, and the average number of trees 1 to 3 inches in diameter are all greater on slightly podzolized soil than on podzol and swampy podzol soils (table 1 and 2).

The average volume per care of all-aged virgin hardwood stands (trees 100 to 300 years old) on slightly podzolized soil sometimes is as great as 12,000 board feet. The volume of hardwood stands on podzol is somewhat less. The hardwoods on swampy podzol produce 8,000; the coniferous-hardwood type on muck, 6,500; and the cedar stands on woody peat, only 4,000 board feet per acre.

It is, of course, not known whether these growth advantages in favor of the slightly podzolized loam will be maintained after the virgin stand has been treated silviculturally, but it is reasonable to expect that they will be.

SOILS AND FOREST MANAGEMENT

The soils discussed are adapted to different tree species, and show different actual and potential productivity; therefore, they require different types of forest management.

Slightly podzolized soils possess adequate moisture, perfect aeration, and an abundance of mineral plant food, and are well suited to forestry of a purely commercial character. Such soils will produce excellent stands of hardwoods. They are even better adapted to a mixture of hardwoods and conifers. The hardwoods tend to reproduce themselves no matter what system of cutting is used, but the valuable conifers must be introduced artificially if they are to

TABLE 1

Average height for sugar maple growing on slightly podzolized, podzol, and swampy podzol soils

DIAMETER BREAST HIGH	AVERAGE HEIGHT OF DOMINANT TREES ON SOILS INDICATED*					
	A	B	C	D	E	F
inches	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*
10	75	65	58	66	67	72
12	79	71	62	72	73	78
14	84	75	65	76	78	82
16	88	79	69	80	82	87
18	91	82	72	83	85	90
20	94	85	74	86	88	93
22	96	87	75	89	90	96
24	98	89	..	91	93	99
26	100	91	..	93	95	101
28	102	93	..	..	97	104
30	103	95	..	..	..	106
32	104	96	..	..	..	108

* A. Slightly podzolized soil—Dukes, Michigan. Basis for values, 95 trees; average height 92 feet; standard error 4.5 feet; standard deviation 8.5 feet; alienation index 0.53; correlation index 0.85.

B. Podzol—Dukes, Michigan. Basis for values, 82 trees; average height 85 feet; standard error 6.3 feet; standard deviation 9.6 feet; alienation index 0.66; correlation index 0.75.

C. Swampy podzol—Dukes, Michigan. Mixed hardwood-coniferous forest type. Basis for values, 16 trees; average height 69 feet; standard error 4.1 feet; standard deviation 6.5 feet; alienation index 0.63; correlation index 0.78.

D. Swampy podzol—Dukes, Michigan. Ground cover principally ostrich fern. Basis for values 22 trees; average height 80 feet; standard error 4.5 feet; standard deviation 9.5 feet; alienation index 0.47; correlation index 0.88.

E. Podzol—Skandia, Michigan. Basis for values 20 trees; average height 83 feet; standard error 4.4 feet; standard deviation 9.7 feet; alienation index 0.45; correlation index 0.89.

F. Podzol without hardpan—Au Train Lake, Alger County, Michigan. Basis for values 32 trees; average height 91 feet; standard error 7.6 feet; standard deviation 12.5 feet; alienation index 0.61; correlation index 0.79.

make up any appreciable part of the new stand. A clear cutting of the old stand and immediate reforestation with valuable conifers (Norway spruce, white spruce, and white pine) accomplish this end. Such a method, however, would make a second cut impossible for a great many years to come, and would be objectionable if sustained production is desired. A gradual selective cutting and underplanting in the openings should accomplish both

purposes. The first selective cuttings should open up the stand as little as possible in order to discourage the growth of sprouts, and preserve the present ideal conditions of soil and humus. In either case, the forest would be converted into mixed stands of planted conifers and naturally reproduced hardwoods.

Podzol soils are characterized by slow humification, and a deficit of mineral nutrients. Because of the impervious nature of the subsoil, the upper layer of podzol remains wet and cool in spring. This may shorten the growing season to a slight degree. During the hot season of summer, the highly colloidal illuvial layer breaks the movement of capillary water, and vegetation often

TABLE 2

Total basal area per acre for stands growing upon different soil types

KIND OF SOIL	ENTIRE STAND DIAMETER 1-35 INCHES B.H.		ADVANCED REPRODUCTION DIAMETER 1-3 INCHES B.H.	
	Total trees	Basal area	Total trees	Basal area
		sq. ft.		*sq. ft.*
Slightly podzolized soil	940	220	750	9.4
Slightly podzolized soil	768	197	640	6.4
Slightly podzolized soil	820	198	644	8.8
Average*	870	209	700	8.5
Podzol	398	140	264	3.6
Podzol	636	125	494	3.9
Podzol	715	153	575	7.9
Average†	557	135	418	4.4

* Weighted average based on 75, 1/50-acre plots. Approximately 95 per cent of total trees per acre are sugar maple.

† Weighted average based on 65, 1/50-acre plots. Approximately 82 per cent of total trees per acre are sugar maple.

suffers from drought. These features become especially pronounced after clear cutting. For this reason selective cutting is the better method of forest management on these soils. From the standpoint of soil improvement, a pure hardwood stand with a predominance of sugar maple is here the best type of forest cover. Yellow birch should also be encouraged, since it is one of the more valuable trees of the hardwood type. In order to hasten the decomposition of raw humus, fairly heavy partial cuttings should be made. However, along the boundaries of stands and at other places where the timber is exposed to strong winds, logging should be limited to defective or over-mature trees. Particularly is this true of stands on podzol with a hardpan layer, for here the

root systems are very superficial and the trees are especially subject to windthrow.

Swampy podzol soils are not well suited to the production of hardwoods. This is particularly true with respect to sugar maple, for on swampy podzol this species grows slowly, has poorly-shaped stems, and shows a high percentage of cull. The reason for this lies chiefly in the insufficient aeration of the soil. Under such conditions, the hardwood species, excepting yellow birch, should be replaced gradually by the conifers, which are better able to stand soil stagnation. White spruce, Norway spruce (*Picea excelsa*), and balsam fir are the most valuable commercial species adapted to this soil. The conversion of the forest can be accomplished through a thinning and an underplanting. Because of the danger from early and late frosts and "heaving," the mound method of planting will have a great advantage on this site. There is apt to be less heaving in spring planting.

Muck soils usually support stands of little commercial value. Nevertheless, from the standpoint of conservation, the preservation and the improvement of the forest cover on these soils are essential. The mixed hardwood-coniferous stands in the alluvial valleys, with their accompanying dense growth of shrubs and grasses, and running water furnish an ideal refuge for game. For this reason, when a selective cutting or thinning is made, the secondary trees and shrubs which supply food for birds and animals should be protected. Available firewood, pulpwood, and conifers for christmas trees should be cut during the winter months. This disturbs the game less, and is the most practical time to log wet ground.

Woody peat ordinarily supports only one species of commercial value—northern white cedar. This may be cut wherever it is available. The only silvicultural requirement is to leave enough healthy, mature trees over the area to secure natural reproduction. If stands of this type contain some balsam fir and spruce, these species should be protected for pulpwood.

SUMMARY

An ecological subdivision of the Upper Peninsula Experimental Forest at Dukes, Michigan, was made in order to obtain a physical basis for carrying on intensive silvicultural management and investigations. Natural elements of topography, such as hill tops, slopes, valleys, basins, areas with a high water table, and areas subject to overflow were blocked out. Five soil types were mapped; viz., (*a*) slightly podzolized loam, (*b*) loamy podzol, (*c*) swampy podzol, (*d*) muck, and (*e*) woody peat. Soils were correlated with forest growth and herbaceous vegetation, and five soil-forest sites recognized. They are:

SOIL TYPE	FOREST TYPE	FLORISTIC TYPE	PRODUCTIVITY
Slightly podzolized loam	Upland Hardwood Type (sugar maple, basswood, elm, etc.)	Acer-Nudum	High
Loamy podzol	Hemlock-Hardwood Type (hemlock, yellow birch, sugar maple, etc.)	Clintonia-Lycopodium	Medium to high
Swampy podzol	Lowland Hardwood Type (sugar maple, red maple, yellow birch, elm, black ash, balsam fir, white spruce)	Fern Type	Low
Muck	Hardwood-Conifer Swamp Type (red maple, aspen, yellow birch, white spruce, black spruce, balsam fir, tamarack, alder, and willow)	Urtica-Gallium	Low
Woody Peat	Cedar Swamp Type (white cedar, balsam fir, spruce, and some hardwoods)	Oxalis	Very low

Upon the basis of the information obtained, the experimental area was subdivided into ecologically uniform compartments, their boundaries were surveyed and blazed, and maps were prepared. This subdivision insures that future differences in composition and growth of stands will result specifically from silvicultural treatment, and not from the co-influence of soil and physiographic features. Thus, a safe, broad application of the results of these treatments becomes possible, and since permanent profile records were made during the course of this study, the influence of soil upon different cuttings, thinnings, and plantings can be observed, as well as the influence of different silvical treatments and tree species upon the soil itself.

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PLATE 1

Soils of the Upper Peninsula Experimental Forest

(a) Slightly podzolized loam, (b) loamy podzol with ortstein, (c) swampy podzol with ortstein and gley, (d) swampy podzol without ortstein, (e) muck upon alluvial sand, (f) muck upon morainic drift, (g) woody peat.

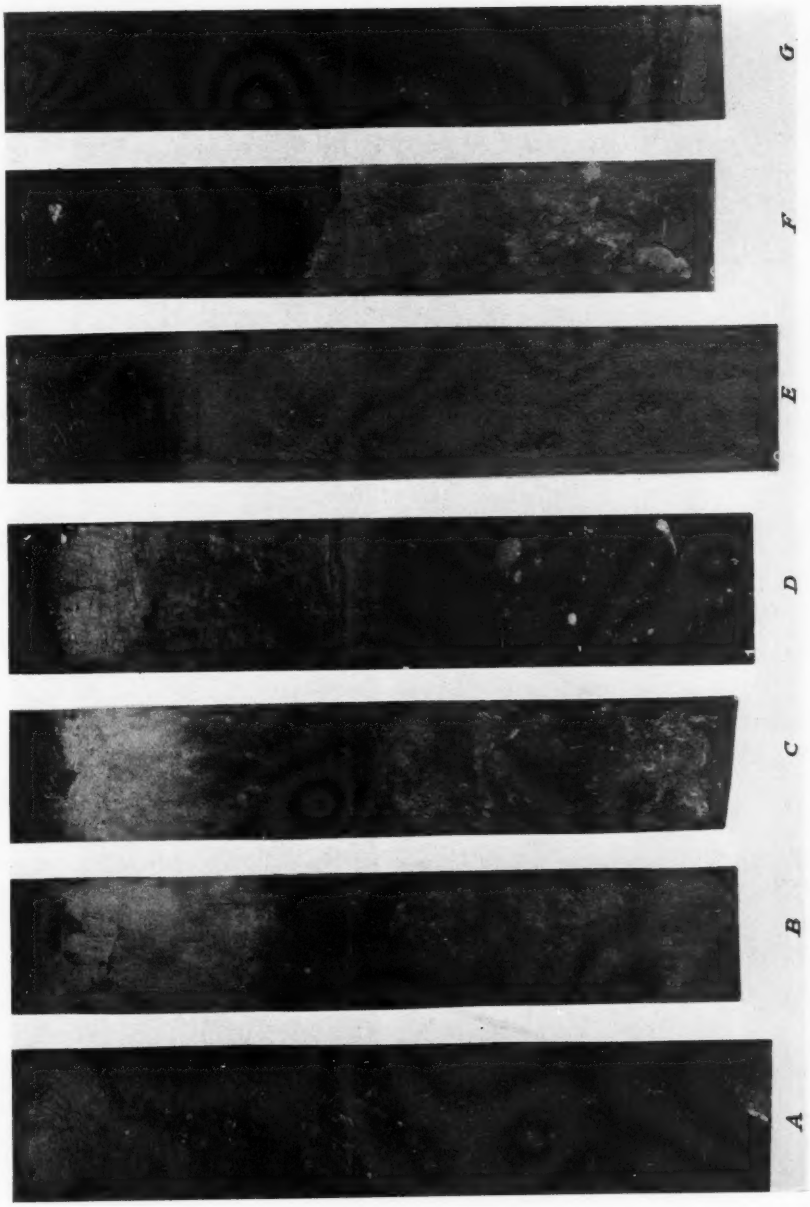
G
F
E
D
C
B
A

PLATE 2

GROUND VEGETATION OF THE UPPER PENINSULA EXPERIMENTAL FOREST

(a) Acer-Nudum type, (b) Clintonia-Lycopodium type, (c) fern type, (d) Oxalis type

B
D
A
C

THE MICROFLORA OF KAZAKSTAN SANDS (CENTRAL ASIA)

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One of the problems of the microbiological division of the Kazakstan Experiment Station of the institute for scientific investigation and study of India rubber was to investigate the microflora in the rhizosphere of the rubber-producing *Chondrilla ambigua, Ch. pauciflora, Ch. brevirostris.* Microbial counts were made by the Winogradsky method to determine the fluctuation in the number of microbes with the soil depth up to the point where the Chondrilla roots begin to branch out.

It was found expedient to reduce the amount of the fractions required by the Winogradsky method from 5 to 3 gm. In place of three sediments and two suspensions, two and one respectively were prepared by shaking 1 gm. of soil in 30 cc. of water and distributing the mixture in three test tubes. The other departure from the Winogradsky method consisted in increasing the number of counts. Instead of 20 fields, 50 were counted. Whenever the original count was questionable it was repeated.

The root system of Chondrilla proved to be extremely long and complicated, reaching the ground waters. The roots constantly change their direction, turning round an axis, making loops and all kinds of bends. At a certain depth, two or three long side roots branch out from the central root in a very irregular and tangled manner. The main root, like the side ones, looks like a long whip with a number of branches. These roots are easily broken and, remaining in the sand, render the work very difficult.

The depth of the water table varies with the topography. In the steppe it is generally found at a depth of 300 to 350 cm. but in low places and in the hollows of sandy hillocks (sand drifts not fastened by the vegetation) it is not lower than 200 cm. The distance from the top of a sandy hillock to the water table is 5 to 6 meters, depending on the height of the hillock. In general, however, the level of the water table does not fluctuate greatly on a smooth topography.

In its upper layers the soil is penetrated by the roots of various plants. The roots of most of the plants, except Chondrilla, stop at a depth of 50 to 70 cm. The entire main root of Chondrilla is covered with smooth brown cuticle which, together with the absence of short side roots, indicates that it does not utilize the moisture of the upper layer of the sand, as do the roots of other plants. The central root with its few long side rootlets, which are also covered with cuticle, branch out upon reaching the water table.

The soil samples were usually taken with sterilized aluminum tumblers near the root or from the root itself, the sand from which was shaken directly into an aluminum tumbler. If the root was lost, the soil sample was taken from the walls or the bottom of a pit. Sometimes a botanical scoop that had been wiped with a piece of sterilized cotton dipped in alcohol was used. Generally, the soil samples were sifted through a 1-mm. sieve. The samples taken near or from the water bearing layer, however, were not sifted as they represented liquid mud. The samples were examined during the first 2 or 3 days. The pH, determined colorimetrically by the Michaelis method, fluctuated from 7.5 to 8.5 but more often between 8.0 and 8.5.

The temperature of the water-bearing layer was found to be 12°C.; at 20 cm. above the water-bearing layer it was 14°C. The temperature of the superficial layer varies with the temperature variations of the air.

The results of the microbial counts lead to the following conclusions. There are two maxima; one near the surface at a depth of 5 to 20 cm., the other near the water-bearing layer at a depth of 175 to 200 cm. The bacilli often surpass the cocci in numbers. At the same time the numbers of bacilli and Azotobacter-like cells change more or less regularly with depth, and their quantity depends upon the general number of microbes. The number of cocci varies irregularly; sometimes the cocci are completely absent. The counting of other forms is generally difficult because many of them cannot be fixed with alcohol (spores) or they are destroyed during the fixation (infusoria).

Sometimes an unexpected rise or depression was noted in the number of microbes at a certain depth. For instance, in the second pit (table 1) there was a comparatively large increase at a depth of 85 cm.; in the fifth pit[1] a depression in the number of microbes at a depth of 130 cm. was observed; in the seventh, an unexpected increase in the numbers was noted at a depth of 110 cm.; in the eighth pit the increase was observed at a depth of 100 cm. Disregarding the fluctuations, there appeared, with sufficient clarity, two maxima as noted in the foregoing.

The low count of the superficial maximum and decrease in the upper layers of the soil of the sixth pit may be explained partly by the influence of the season; the pit was dug on July 30, when the upper layers are more likely to suffer from effects of desiccation. In the seventh pit, which was dug in shifting sands, the upper layers were not investigated because of the crumbling and also because of the seasonal influence manifested when digging was completed, on August 9. The season also influenced the superficial maximum at a depth of 20 cm. of the second pit, which also was dug in shifting sands just after the May rains on June 3. The third pit was also made in shifting sands.

Some fluctuations in the number of microbes at different depths also may be explained by the season of digging. The pit dug in May, because of the rains, shows an upper maximum nearer the surface than does the pit dug in August

[1] Although detailed information was obtained on eight pits, data on only four pits are presented in table 1 for purposes of illustration.

TABLE 1

The number of microbes in 1 gram of soil

DEPTH	TOTAL NUMBER OF MICROBES	BACILLI	COCCI	AZOTOBACTER-LIKE CELLS	OTHERS
cm.	*thousands*	*thousands*	*thousands*	*thousands*	*thousands*
		First pit			
5	30,675	.....	3,500	27,000	175
15	22,000	2,500	5,000	14,000	500
30	7,300	1,300	.....	6,000	.....
65	13,000	5,000	2,500	5,500	.....
105	28,400	10,500	1,500	8,000	8,400
		Second pit			
20	39,000	9,500	500	27,000	2,000
35	10,000	1,500	.....	7,500	1,000
55	42,000	5,000	6,000	27,000	4,000
85	86,000	11,500	26,000	42,000	6,500
105	28,600	4,500	20,500	3,500	100
120	20,700	2,000	10,000	8,000	200
135	25,200	6,000	9,000	10,000	200
165	53,300	13,000	9,000	31,500	300
195	28,000	8,000	.....	19,000	1,000
		Sixth pit			
5	14,000	3,000	500	10,000	500
30	6,000	1,000	.....	3,000	1,500
50	39,000	22,000	8,000	7,500	1,500
60	14,500	6,000	1,500	5,000	2,000
(A)100	13,000	9,500	500	2,000	1,000
(B)100	21,000	9,000	4,500	7,000	500
140	19,000	4,500	1,000	12,000	1,500
180	23,500	9,000	1,500	10,500	2,500
255	45,500	7,500	2,000	33,500	2,500
300	19,000	2,000	2,500	13,500	1,000
320	40,500	8,500	3,000	29,000	200
345	11,000	6,000	500	3,000	1,500
		Eighth pit			
5–10	70,000	6,000	13,000	41,000	10,000
20–25	36,500	3,500	3,500	29,000	500
60	28,500	4,000	1,000	22,000	1,500
100	73,000	4,500	26,500	41,000	1,000
130–140	53,000	5,000	6,000	36,500	5,500
(A)170	39,500	2,500	1,500	20,000	15,500
(B)170	60,000	11,000	2,500	44,500	2,000
200	62,000	26,000	6,000	25,000	5,000
250	81,000	22,000	2,500	52,500	4,000
300	51,000	17,500	4,000	20,000	9,500

when the upper strata of the soil had dried out considerably. The lower maximum appears on the average at the 200-cm. depth. The third pit, having a depth of 350 cm., did not reach the water-bearing stratum; its maximum is at the 200-cm. depth. In the fourth pit, where the water-bearing layer is at a depth of 275 cm., the maximum is at the 200-cm. depth. In the fifth pit, where the water-bearing layer is at a depth of 175 cm., the maximum is at depths of 100 and 175 cm. The maximum at the depth of 175 cm. coincides with the water-bearing stratum. The proximity of the water-bearing layer to the surface may create such conditions of aeration and temperature that the maximum appears at the water level. In the sixth pit, where the water-bearing stratum is at a depth of 375 cm., the maximum is at a depth of 255 cm. In the seventh pit the lower maximum again coincides with the water-bearing layer at a depth of 200 cm. In the eighth pit the water-bearing layer is at a depth of 300 cm., and the lower maximum is at a depth of 250 cm. This is a typical position of the lower maximum in the strata overlying the water-bearing layer. Except for the fifth and seventh pits, the lower maximum does not coincide with the water-bearing layer.

Sometimes the roots do not reach the water-bearing stratum, terminating slightly above it. In the sixth pit the fine rootlets terminate at a depth of 345 cm., 20 or 30 cm. above the real water-bearing stratum. In the eighth pit the rootlets reached a point in the soil where it appeared like mud. The last deep samples had to be taken outside of the root zone.

In order to clarify the assertion that Chondrilla exerts effects on the quantitative composition of the microflora in the rhizosphere, a seventh pit was dug, known as the "empty pit," since the excavation was not done along the rhizosphere. Around a Chondrilla bush a simple wide pit was dug in the usual manner. The roots were cut by the spade with the walls of the pit at a distance from the bush and not in contact with the root system. The only departure from the normal was the fact that the maximum coincided with the water-bearing stratum, which might be explained by the nearness of the water-bearing layer to the superficial soil layers from which it was separated by a distance of 200 cm. The same results are apparent in the fifth pit where the digging was accomplished along the root and where the lower maximum also coincided with the water-bearing layer at a depth of 175 cm.

One common trait of the fifth and the seventh pits was that both were dug in the middle of a circle of sand hillocks, in a place where the water table was lower than usual for the steppe. From the numbers showing the change of microbes according to the depth, it is impossible to guess which of the pits was dug along the rhizosphere and which was dug outside of it. The coincidence of the maximum in microbes in relation to the water table points to the conclusion that both pits were dug under the same conditions of soil topography. Each pit, in certain parts, proved to be an "empty one"; in the process of digging sometimes not only the rootlets were lost, but also the medium parts of the root. That is why one could foretell that there would be no substantial

difference between the empty and normal pits, just as there was no difference between the layers close to the rhizosphere and those out of contact with it.

In the sixth pit at a depth of 100 cm., one sample of soil from the principal root was taken with a scoop, and a parallel sample was taken from the vertical wall of the pit not in contact with the root. In the soil sample taken along the root there were 13,000,000 bacteria and in the sample from the wall 21,000,000. In the eighth pit at a depth of 170 cm., sample A (table 1) was taken out of contact with the rhizosphere, the dark spongy mass also being taken with it. Sample B was taken from the root and beside the root. Sample A contained 39,500,000 microbes, sample B, 60,000,000 microbes, just the reverse of the data obtained from the sixth pit. The smaller number of microbes found on the wall of the pit was probably due to the inclusion in the sample of the dark mass, which, according to the experience with the fifth pit, contains a negligible number of microbes.

The numbers of microbes at the various depths lead to the conclusion that the rhizosphere of Chondrilla does not appreciably influence the microflora of the surrounding soil. If it did, the data on the number of microbes in the different strata of the soil would not show the marked changes due to seasonal differences. All of the root is covered with cuticle which excludes the influence of enzymes on the surrounding soil. There is a possibility, however, that Chondrilla influences the quantity of microbes in the rhizosphere of the rootlets where diffusion of the fermenting juices from the cells is possible. But just at the termination of the root zone the maximum of microbes is not observed, because these root endings are dipped in the water-bearing layer. Evidently the low temperature and a hampered condition of aeration do not favor a rich development of microbes in the region of root endings.

The experiments described in this paper, when examined by the indexes laid down by Winogradsky, do not indicate that Kazakstan soils have a richly populated microflora. Winogradsky recognizes three kinds of soils: (*a*) soils with a rich microflora which contain more than 1 milliard of microbes in 1 gm. of soil; (*b*) the medium soils, which contain not more than 1 milliard in 1 gm.; and (*c*) the poor soils, which contain not more than 0.5 milliard of microbes in a gram of soil. From this point of view, the Kazakstan soils, in which only some tens of millions of microbes were found in a gram of soil, must be considered as poor.

The microflora is classified by the Winogradsky method into bacilli, cocci, Azotobacter, etc. In these experiments the microbiologist will doubt the presence of Azotobacter in the deep layers. Of course the morphological similarity alone is not enough evidence that the organisms are Azotobacter cells. At this point, however, it is well to recall the work of Kononova,[2] who

[2] M. M. Kononova. The vertical distribution of Azotobacter and nitriferous organisms in the soils of certain districts of Central Asia. The collection of works of the microbiological department of the laboratory investigations of AK-Kavak's experimental station of irrigation, issue 7th.

found Azotobacter in the soils of Bukhara at a depth of 2 meters. Kononova considered cultivated soils where Azotobacter penetrated great depths. The soils of the Irrigation Experiment Station have been under irrigation for centuries. In Kazakstan the problem is more complicated because the experiments were conducted on the semi-desert soils which have never been worked before. How the Azotobacter penetrated these soils is not at all clear.

It is interesting to note that preparations made of other Kazakstan soils, Mouiun-Kooms, Kara-Kooms, and Kurtins sands, show characteristics similar to those recorded in these experiments. They contain many bacillary forms, few cocci, and cells resembling Azotobacter. The latter were also found in the preparations of the samples of soil sent from the hills of Kara-Tohand. It was there that the eudemic rubber-bearing tan-Saghyz was discovered.

Future experiments will show whether the so-called Azotobacter organisms are capable of fixing nitrogen. Kononova, who isolated Azotobacter from the deep soil layers, states: "The presence of Azotobacter at such a depth is incompatible with our usual notion about it as an aerobic organism." Heinze maintains that there is no soil without Azotobacter. Shulgina[3] points out that the virgin soils of Turkestan contain as many Azotobacter organisms as the cultivated soils.

A question was raised as to the accuracy of the Winogradsky method. The experiments recorded do not answer this question. The method presents considerable difficulties. The least of these is the washing off of the first sediment and the greatest is the ability to remove from the 10 cc. of liquid a drop which will contain a representative quantity of microbes for the given fraction. Many bacteria are adsorbed by the soil particles and in such a case they are not noticed at all or are seen dimly and cannot be counted. One must agree with Shulgina and her collaborators that the numbers obtained by direct microscopical methods are considerably reduced, as it is impossible exactly to discern separate species among the groups of bacteria adsorbed by the soil particles. In comparison with other methods the direct microscopic method, in spite of all its defects, gives the numbers more correctly than, for instance, the plate method.

The microbiological investigation of the Kazakstan sands shows that even those semi-desert sands are not free from a definite microflora.

[3] Shulgina, Berseneva, and Norkina 1930 Materials to microbiological characteristics of the Turkestan soils. *Works of the Institute of Agricultural Microbiology*, vol. 4. Omelianskv 1915 About the spread of nitrogen fixing bacteria. *Arch. Biol. Sci.*, vol. 18.

STUDIES ON TROPICAL SOIL MICROBIOLOGY: II. THE BACTERIAL NUMBERS IN THE SOIL OF THE MALAY PENINSULA

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In the last decade, in both Europe and America, increasing attention has been paid to the enumeration of the microörganisms in the soil. Such work has usually been carried out by the plate-counting method, the reliability of which has been investigated, under temperate conditions, by Fisher, Thornton, and Mackenzie (5) in England and by Waksman (12, 13) in America. This method has its limitations, but, by its use, fairly reliable estimates can be obtained of the numbers of certain groups of aerobic microörganisms present in the soil. It need hardly be stressed, however, that results obtained from a few isolated determinations may be totally misleading.

As a result of investigations by the aid of the plate-counting method by Cutler, Crump, and Sandon (4) and by Thornton and Gray (11) at Rothamsted, the seasonal and diurnal fluctuations normally occurring in the numbers of soil microörganisms appearing on the agar plates are fairly well known for temperate regions. There is general evidence that bacterial numbers and activities are greatest during the spring and autumn, and it is also apparent that, in general, there are two maxima during the day, one occurring about 10 a.m. and the second in the evening. It might be anticipated that variations in the numbers of soil microörganisms would be closely related to the temperature and moisture-content of the soil, but definite evidence on this matter is lacking. Thornton and Gray (11) could find no correlation between changes in bacterial numbers and the soil moisture-content, and but rarely were soil temperature changes reflected in fluctuations in the bacterial population: this investigation, however, was primarily concerned with diurnal variations. If the fluctuations in the numbers of soil microörganisms are largely the reflection of variations in the temperature and soil moisture-content then, in equatorial regions such as Malaysia where the monthly variations in temperature are negligible and the rainfall is high and, under usual circumstances, soil moisture cannot become a limiting factor, it would be anticipated that the numbers of soil microörganisms present per unit of soil would approach a constant value. As far as could be traced no systematic work of this nature

[1] This investigation was carried out at the Rubber Research Institute of Malaya by the writer in his capacity of bacteriologist. Thanks are due to the director of the institute for permission to publish the results.

had been carried out in the tropics previously and it appeared highly desirable to investigate this matter when the opportunity presented itself.

A further reason for examining the fluctuations in population of soil micro-organisms under tropical conditions is that variations in the numbers are often invoked to explain certain changes which follow the felling and clearing of tropical forests. Since many of the statements found in the literature concerning the biological changes consequent upon clearing are highly speculative, the subject merits scientific investigation.

THE SUNGEI BULOH EXPERIMENT

In the early months of 1929 a large plot (block 15) on the Experiment Station of the Rubber Research Institute of Malaya at Sungei Buloh, Selangor, F. M. S., was cleared of primeval forest and subsequently planted with rubber seedlings and a leguminous cover. During 1929 and the year following soil samples were taken at approximately weekly intervals, and the numbers of microörganisms per 1 gm. of moist soil were determined by the usual plate-counting method. Sampling was always carried out at 10 a.m. when the bacterial population of the soil is considered to reach a maximum. Each week two samples of soil were taken from random sites on block 15: the surface soil was scraped off and a sample was taken to include the layer from 1 to 4 inches below the surface. Plates were poured when the samples were precisely 24 hours old, and Thornton's mannite-agar medium (10) was employed. Three or four plates, latterly always four, were poured for each sample. At first dilutions were made of 1/1,000, 1/10,000 and 1/100,000, but since it was found that the 1/1,000 dilutions were always countable, the higher dilutions subsequently were omitted. All colonies were counted and, in this paper, the term "bacterial counts" must be understood to comprise fungi and actinomyces, as well as bacteria. The plates were incubated at laboratory temperature (26°–29°C.) for 5 days before counting. Preliminary trials showed this period to be the optimum for the purpose as longer incubation resulted, not in the appearance of further colonies, but in the overgrowth of certain fungal colonies.

Briefly, the history of block 15 is as follows: The virgin forest was felled in March 1929, and the timber and brushwood were roughly collected into heaps and burnt. In the latter part of March and during April the rainfall was heavy and a condition almost approaching water-logging obtained: efficient drainage was not completed until October. "Burning-off" operations first took place in the beginning of June and then, after a lapse of 3 weeks or so, were resumed in the middle of July and continued until well into September. From November onwards a cover of a low-growing leguminous plant, *Centrosema pubescens*, was established and seedlings of *Hevea brasiliensis* were planted in December. In the latter half of 1930 the growth of the cover was luxuriant and the soil was strongly shaded. It is to be regretted that more counts were not made while the soil was under forest, but this unavoidable omission was in some measure rectified by occasional sampling from the forest reserve surrounding the experiment station.

The most striking of the general climatic features of the Malay Peninsula are the uniform temperature and high humidity [see Haines (6) where meteorological records are discussed from the viewpoint of the agriculturist]. The only noticeable seasonal variations are slight differences in the rainfall, definite maxima occurring about April and November; but the wettest period of the year usually ranges from October to January. The annual rainfall is over 100 inches and the rainfall intensity may often be considerable.

The mean air temperature is approximately 80°F. with a range of about 3°. In virgin forest the soil temperature is 75°F., the daily variation at the surface being less than 1°. On the other hand, Haines found that the mean soil temperature under bare ground at the experiment station was some 6° to 15°F.

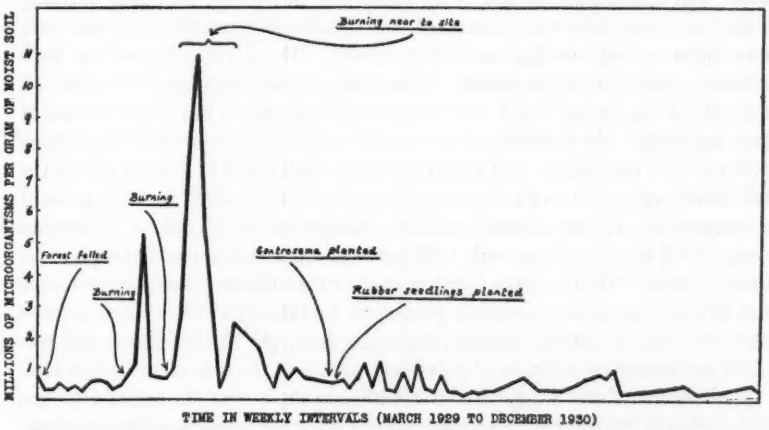

FIG. 1. FLUCTUATIONS IN BACTERIAL NUMBERS ON BLOCK 15 OF THE SUNGEI BULOH EXPERIMENT STATION DURING THE CONVERSION OF VIRGIN FOREST INTO A RUBBER PLANTATION

higher, the greatest daily range found being 35° and, on occasions, the soil temperature at the surface rose to well over 100°F. A diminution of some 3° or 4° in the mean temperature of the soil surface was produced by the cultivation of a low-growing cover plant.

The relative humidity of the atmosphere is usually over 90 per cent of the saturation value, but it may fall to figures in the sixties during the warmer hours of the day.

It became evident in the earlier stages of the experiment that the proportion of fungi to bacteria is much higher, and the total numbers of soil microörganisms found are considerably lower, than in temperate regions.

The results obtained for the counts on the Sungei Buloh plot are expressed graphically in figure 1. The points shown represent the geometric means for two samples taken at the same time on the same day, the value for each

sample being obtained by taking the arithmetic mean of the plate counts for the sample in question. This procedure is recommended by Robertson (9) and has much to commend it; reference will be made to this matter, however, later.

From figure 1 it is evident that the results were uniformly low throughout the 2 years except for short periods following the "burning-off" operations when large increases in the population were found. Usually the effects of a burn-off were localized but, on occasions, the wood-ash was wind distributed. That the increased population is attributable to the presence of wood-ash and not to any "partial sterilization" effect produced by the fires is certain because high counts were obtained on sites where the wood-ash had been blown by the wind, and also under the site of an actual fire on the day following burning. This rise in numbers was evanescent, and conditions returned to normal very soon after actual burning operations ceased. The explanation of the high counts appears to be not entirely a question of neutralization of an acid soil (the pH of the Sungei Buloh soils was usually below 5.0) but also a matter of base exchange. An experiment was carried out in which wood-ash, containing 6.99 per cent potassium, was added to Sungei Buloh soil in a plant pot in the laboratory and at intervals the soil was watered with distilled water in amount corresponding to the normal rainfall. Altogether 12.39 gm. of potassium were added to the soil, but only 0.42 gm. was recovered in the drainage water after 27 days. On the other hand, it is clear that the increased population is not directly due to the presence of potassium, for laboratory experiment showed that the rate of carbon dioxide production from the Sungei Buloh soil was quite unaffected by addition of potassium sulfate at the rate of 5 cwt. per acre.

The results of the Sungei Buloh experiment show that the microbiological population of the soil remains approximately constant throughout the processes of felling, clearing, and planting, and only as a result of drastic burning operations are the numbers of soil microörganisms materially affected. For the greater part of 1929 the soil was uncovered and exposed to the tropical sun, whereas during the latter part of 1930 it was shaded by a dense growth of *Centrosema pubescens*, a change of treatment which has not been reflected in fluctuations in the numbers of soil microörganisms present.

In table 1 are given the distribution frequencies of the results of the Sungei Buloh experiment, and when these are expressed graphically a J-shaped curve is obtained.

If, instead of taking the actual figures for the counts, the logarithms of these values are used, the plot of the distribution frequencies is a bell-shaped curve, characteristic of a population normally distributed, but there is, in addition, a smaller curve containing classes of higher values (table 2). These high values falling outside the principal curve were all obtained during the period when "burning-off" operations were in progress and there can be no doubt that they are to be attributed to the presence of wood-ash on the soil. The results clearly indicate that the slight variations found in the bacterial counts from

soil on the experiment station throughout the 2 years are of little significance except in the case of the samples taken during the period of burning operations. No correlation was found between numbers of microörganisms and rainfall.

TABLE 1

Distribution frequencies of the bacterial counts from the soil on Sungei Buloh Experiment Station, 1929–1930

THOUSANDS OF MICROÖRGANISMS PER 1 GRAM OF MOIST SOIL	FREQUENCY
0– 200	21
201– 400	31
401– 600	29
601– 800	18
801–1,000	7
1,001–1,200	7
1,201–1,400	3
1,401–1,600	4
1,601–1,800	0
1,801–2,000	2
2,001–2,200	0
2,201–2,400	1
2,401–2,600	0
2,601–2,800	1
2,801–3,000	0
Above 3,000	10

TABLE 2

Distribution frequencies of the logarithms of the bacterial counts from the soil on Sungei Buloh Experiment Station, 1929–1930

LOGARITHMS OF THOUSANDS OF MICROÖRGANISMS PER 1 GM. OF MOIST SOIL	FREQUENCY
1.61–1.80	1
1.81–2.00	1
2.01–2.20	6
2.21–2.40	20
2.41–2.60	24
2.61–2.80	31
2.81–3.00	24
3.01–3.20	13
3.21–3.40	3
3.41–3.60	2
3.61–3.80	5
3.81–4.00	3
4.01–4.20	0
4.21–4.40	0
4.41–4.60	1

Microbiological examination of other soil samples in the Malay Peninsula

A number of soil samples were taken from various other sites in the Malay Peninsula (primary and secondary forest, mangrove forest, coastal peat soil, garden soil, and other rubber estates), and the numbers of microörganisms developing on the plates were determined in precisely the same manner as before. The results obtained on the experiment station were confirmed: in general, the total numbers were low, almost invariably fungi predominated over bacteria and, curiously enough, in three of the four instances where values of over 1 million were found, earthworms were present. The earthworm, *Pontoscolex corethrurus* Fr. Müll., is by no means abundant in Malaya and it was found on but few occasions during the course of soil sampling.

TABLE 3

Distribution frequencies of the logarithms of all the bacterial counts obtained in the Malay Peninsula

LOGARITHMS OF THOUSANDS OF MICROÖRGANISMS PER 1 GM. OF MOIST SOIL	FREQUENCY
1.61–1.80	1
1.81–2.00	4
2.01–2.20	11
2.21–2.40	30
2.41–2.60	37
2.61–2.80	38
2.81–3.00	30
3.01–3.20	15
3.21–3.40	4
3.41–3.60	2
3.61–3.80	5
3.81–4.00	3
4.01–4.20	0
4.21–4.40	0
4.41–4.60	1

A feature of the investigation was the almost complete absence of colored colonies on the plates. One species, *Rhodococcus prometheus* Cbt. (2), found in forest soil on one occasion only, produced a pigment which was carmine-red in acid, and yellow in alkaline solution, the change being reversible.

As in the case of the experiment station results, for each sample the arithmetic mean of the respective plate counts has been calculated and the distribution frequencies of the logarithms of the whole of the counts obtained in the Malay Peninsula (i.e. those from the experiment station plus all the others) are given in table 3. The histogram is characteristic of a normally distributed population if some eight or nine high values be excepted. These high results, which ranged between 4,800 and 30,000 in actual values, were all taken during the period of "burning-off" operations on the experiment station.

The results emphasize the advantage of employing the logarithmic and not the arithmetic values of the counts. The arithmetic mean of the experiment station results is 1,168,000, whereas the geometric mean is 557,000. It is evident that the latter value must be much nearer the true mean. The arithmetic mean of the whole of the Malayan counts is 969,000, whereas the geometric mean is 469,000.

The growth of microörganisms takes place according to the bacterial growth curve, and the writer (1) has suggested that this cycle has a much wider application than is generally realized. The normal growth curve is divisible into a number of more or less clearly defined phases: following the initial period of slow growth (phase of adjustment) is a period of rapid growth (phase of increase) which is maintained until the stationary phase of crisis is reached; after this a period of decline sets in and the phases of decrease and readjustment can be recognized. Of these growth periods, the phases of increase and decrease are the most important, for, normally, they are of longest duration and in each case the rate of growth bears an exponential relation to the time. The writer (3) has shown, as a result of work on the evolution of carbon dioxide from soils in the laboratory, that the period between removing the sample from the field and examining it in the laboratory corresponds to the phase of decrease on the bacterial growth curve, during which the decline in numbers is strictly logarithmic. This being so, it is evident that Robertson's suggestion that bacterial counts should be averaged by taking, not the arithmetic, but the geometric mean is based on sound premises.

If the distribution frequencies of the whole of the actual bacterial counts obtained in this investigation are plotted, the values fall on a J-shaped curve and the arithmetic mean of all the results does not coincide with the mode of the curve. On the other hand, in the curve showing the distribution frequencies of the logarithms of the counts the value for the mean of all the samples coincides almost exactly with the mode of the curve, the absence of complete agreement being attributable to the presence of samples taken during "burning-off" operations which pertain to a different population. It may be worth pointing out that the distribution frequencies of the 60 plate counts obtained by Waksman (12, p. 91) for the same soil sample, when plotted, form a skew curve but the plot of the distribution frequencies of the logarithms of these values gives a normal curve in which the mean of the values corresponds to the mode of the curve.

A statistical examination of the data reveals that, although the values obtained on the Sungei Buloh experiment during the period of "burning-off" operations (June to September 1929) are significantly greater than those found during the remainder of the experiment, these latter are not significantly different from the values found for 10 samples from virgin forest. The relevant data are:

	NUMBER OF SAMPLES	MEAN VALUE OF LOGARITHMS OF RESULTS	STANDARD ERROR OF LOGARITHMS OF RESULTS
(*a*) Sungei Buloh Experiment (excluding burning period)	109	2.609	0.0283
(*b*) Sungei Buloh Experiment ("burning-off" period)	27	3.275	0.0878
(*c*) Virgin forest	10	2.553	0.104

At the $P = 0.05$ level of significance, the mean of (*b*) is significantly different from the means of both (*a*) and (*c*), there being no significant difference between these last two.

Calculation of Pearson's constants β_1 and β_2 for the logarithmic values of all the 156 bacterial counts on soils in the Malay Peninsula, other than those carried out during the "burning-off" period at the Sungei Buloh Experiment Station, has shown these to be 0.0001 and 2.57 respectively. For a symmetrical distribution β_1 is zero while β_2 is 3.0 for a normal curve but is smaller or greater according as the curve is platykurtic or leptokurtic. For the logarithmic values of the 60 bacterial counts obtained by Waksman for the same soil sample, referred to in the foregoing, β_1 and β_2 have the values 0.0711 and 2.58. The logarithms of the 30 counts made by Eggleton (4a) on a grassland plot at Jealotts Hill from March to November gave $\beta_1 = 0.0005$ and $\beta_2 = 2.84$ for bacteria and $\beta_1 = 0.0027$ and $\beta_2 = 2.11$ for fungi.

DISCUSSION

As a result of this investigation the important conclusion is reached that, under the usual conditions prevailing in the Malay Peninsula, the number of soil microörganisms in 1 gm. of soil (as determined by the plate-counting method) approaches a constant value of 500,000. This number is very low compared with the values found in temperate countries: for instance, the bacterial counts per 1 gm. of soil obtained by Thornton and Gray (11) for Rothamsted soils ranged between 8 and 50 millions and were usually in the neighborhood of 20 millions. The fact that no significant difference was found between samples taken from soil under virgin forest and from soil on clearings exposed to the sun may be of some importance, for it shows that an appreciable rise in the mean temperature has produced no measurable changes in the microbiological population of the soil.

These results have some bearing on the much debated question in tropical agriculture as to whether dead timber from areas recently cleared of forest should be collected and burnt, or allowed to remain on the site and decay. Almost invariably in Malaysia the timber is "burnt-off," but it is now known that some of the arguments employed by the advocates of this procedure are erroneous. Only one of these arguments need concern us here: it has been

submitted that, by permitting timber to decay on the site of clearing, a considerable amount of readily available soil nitrogen is locked-up as a consequence of the addition to the soil of material with a very high carbon nitrogen ratio. If such a locking-up of nitrogen in the body material of microörganisms occurred it would be reflected in an increased soil microbial population, but the results presented in this paper show that such population increases do not take place. Decaying timber is always present in the forest under natural conditions, and it is now known that the destruction of this material is affected almost entirely through the agency of termites. As a further advantage of "burning-off" it has been suggested that a temporary reduction in the numbers of soil microörganisms must follow this process of "partial sterilization:" this anticipation is entirely wrong.

The results reported here also throw light on a problem of fundamental importance. It has been shown that, under constant humidity factors, the nitrogen content of the soil decreases exponentially with increasing temperature (7, 8). In the Malay Peninsula, the soil temperature in the virgin forest is constant at 24°–25°C. but it may be raised very considerably when the forest is cleared and the soil exposed to tropical sunshine. It is well known that such exposure results in a reduction of the organic matter content as well as in a diminished nitrogen content. The question as to the mechanism by which this reduction of the nitrogen content of the soil is effected is of some importance: it is usually assumed that the increased soil temperature consequent upon removal of the shade of the forest results in increased microbiological activity which, in turn, accounts for the disappearance of readily oxidizable organic matter; but the results given here show that such an explanation cannot be upheld. It seems evident that the fall in the nitrogen content of the soil to a lower level on subjection to higher temperatures must be ascribed to chemical and not to microbiological agency, but this subject will be returned to in the next part of this series of papers.

SUMMARY

It is shown that, under the equatorial conditions prevailing in the humid tropics of the Malay Peninsula, the number of soil microorganisms, as determined by the usual plate-counting method, is constant under all normal conditions and approximates a value of 500,000. The results suggest that fluctuations in bacterial numbers in the soil are primarily functions of changes in the temperature and moisture content and when these factors are maintained constant no variations in bacterial numbers are apparent.

On almost all the plates examined fungi predominated over bacteria, indicating that these organisms play an important rôle in the decomposition of soil organic matter in the humid tropical regions.

The practical consequences of the results are discussed.

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BOOK REVIEWS

Small-Fruit Culture. By JAMES SHELDON SHOEMAKER. P. Blakiston's Son & Co., Inc., Philadelphia, 1934. Pp. xv + 434, figs. 52.

The shift from crops of low to high commercial value per acre has run parallel to specialization and intensification of production. The New England and the Middle Atlantic States have paid increasing attention to the production of small fruits. There has been a rather remarkable expansion in small fruit culture in the Southeast and on the Pacific Coast. It is proper to expect that *Small-Fruit Culture*, offered as a text for instruction and reference work, as well as a guide for field practice, should be welcomed widely.

The author notes that "The text is based on information derived from the extensive but scattered literature; suggestions (heretofore unpublished) from specialists at various institutions; growers' experience; and, the author's own work with small fruits. The practical application is emphasized throughout the text."

The principal sections of the book relate to: Part I. Grape Culture; Part II. Strawberry Culture; Part III. Bramble-Fruit Culture; Part IV. Currant and Gooseberry Culture; Part V. Blueberry Culture; and Part VI. Cranberry Culture. There is a list of 389 references. Teachers in our colleges of agriculture, small-fruit growers, research workers, and others will feel indebted to the author for having brought together much useful material.

Commercial Flower Forcing. By ALEX LAURIE and L. C. CHADWICK. P. Blakiston's Son & Co., Inc., Philadelphia, 1934. Pp. x + 519, figs. 49.

Many new methods of floriculture have come into existence within the present decade. Progressive florists have not been slow in adopting the findings of our research workers in so far as technical data were ready for use in commercial floriculture. The notable progress which has been made by geneticists and plant physiologists, and likewise the contributions for which we are indebted to plant pathologists and entomologists, are playing a more important rôle in commercial floriculture than they did a few years ago. As indicated by the authors: "The object of this concise treatise is to cover the fundamentals involved in the growing of various flower crops used for commercial purposes and deal with them from the viewpoint of practical culture. The treatments recommended follow the routine practice of the better growers, supplemented by a vast volume of experimental work done under the experienced supervision of the authors."

The 27 chapters of the book deal with the following: Status and Development of the Industry; Plant Structures and Their Function: Greenhouse Con-

struction and Heating; Factors Influencing Plant Growth; Soils; Fertilizers; Reproduction; Diagnosing Greenhouse Ills; Major Crops; Minor Crops; Miscellaneous Cut Flower Crops; Bulbs, Corms and Tubers; Flowering Pot Plants; Foliage Plants; Forcing Hardy Plants; Outdoor Crops; Wholesale Marketing; Costs of Production.

The Biology of Bacteria. An Introduction to General Microbiology. By ARTHUR T. HENRICI. D. C. Heath and Co., Boston, etc. 1934. Pp. x + 472, figs. 112.

The present trend toward the better training of our research workers in the biological sciences is manifested in part by the publication of this book. In preparing the treatise, the author, as he himself notes, was guided by the wish to create something that would be "an introduction to general microbiology." In his own words: "This is a textbook to be used by general or nontechnical students who will take but one course in microbiology; or in introductory courses for other students who will be taught particular applications of the science in advanced courses." He says, further:" Above all, I have tried to present the material as *microbiology*, not as agriculture or hygiene—to stress the pure science aspects rather than the applications."

After reviewing the history of bacteriology, the author devotes a chapter to the microscope and microscopy. This is followed by five chapters on a survey of microbic life, devoted to the discussion of protozoa, algae, fungi, bacteria, and the ultramicrobes. The next six chapters are devoted, respectively, to the finer structure of bacterial cells; the growth and reproduction of bacteria; heredity and variation in bacteria; the metabolism of bacteria; the cultivation of bacteria, and the death of bacteria. Chapters XIV and XV are given over to a discussion of infection and immunity, respectively; and Chapter XVI is devoted to bacterial diseases of plants. Chapters XVII to XXIX deal with classification of bacteria; the nitrobacteriaceae; the coccaceae; the spirillaceae; the bacteriaceae; the bacillaceae; the mycobacteriaceae; the actinomycetaceae; the molds, yeasts, and yeast-like fungi; the pathogenic protozoa; the spirochaetales; and the rickettsia and virus diseases.

The work is sufficiently compact to favor its use in one-semester courses of collegiate credit. The author is to be commended for having presented clearly and effectively a subject in which there is a growing interest. The publishers have done their part in making the book attractive.

Commercial fertilizers. Their sources and use. By GILBEART H. COLLINGS. P. Blakiston's Son & Co., Inc., Philadelphia, 1934. Pp. xiv + 356, figs. 85.

The field of commercial fertilizers is a changing one in that new discoveries and technical improvements are calling for adjustments both among the manufacturers and the users of commercial fertilizers. The reader of this book will recognize how much change has occurred even within the last half dozen years in the fertilizer industry. New sources of raw materials have developed, and fertilizer practices have changed for economic as well as other reasons.

The author tells us that "The text is the outgrowth of the author's sixteen years of experience as an experiment station agronomist and teacher of soil, fertilizer and crop courses at the Clemson Agricultural College. For a number of years the subject matter included herein has been presented to classes composed largely of juniors and seniors." He states, further: "This book represents a composite of the opinions and conclusions of authorities within the fertilizer industry, as well as the conclusions of experiment station agronomists, especially in the fertilizer-using territory of the United States.

The book is made up of 15 chapters, dealing with the following subjects: Origin and Development of the Use of Commercial Fertilizers; Source, Production and Use of Sodium Nitrate; Manufacture and Use of Ammonium Sulphate; Manufacture and Use of the Synthetic Nitrogenous Fertilizers; Sources and Uses of Organic Nitrogenous Fertilizers; Sources and Use of the Mineral Phosphates; Sources and Use of Bone Phosphate and Basic Slag; Manufacture and Use of the Superphosphates; Production, Manufacture and Use of the German and French Potash Salts; Miscellaneous Sources of Potash Fertilizers; Sources and Uses of Fertilizers Carrying Essential Elements Other than Nitrogen, Phosphorus and Potash; Uses of Fertilizers Carrying Elements not Accepted as Essential for Plant Growth; Principles Underlying the Use of Fertilizers; Principles Underlying the Purchase of Fertilizers; The Application of Fertilizers and the Influence of Fertilizers on Germination and Seedling Growth. These are followed by a bibliography and author and subject-matter indexes. The author has rendered a distinct service in having made available in textbook form much new information.

Methoden für die Untersuchung des Bodens. II. Teil. By O. LEMMERMANN and L. FRESENIUS. Verlag Chemie, G. m. b. H., Berlin, 1934. Pp. 122, figs. 4.

The first part of *Methoden für die Untersuchung des Bodens* appeared in 1932. It was the intention of the authors, as indicated in the Preface of Part I, to develop a series of treatises devoted to methods of soil investigation. The scope of the work is indicated by the following arrangement of the subject matter: A. The Sampling of Soils; B. The Physical Investigation of Mineral and Organic Soils; C. The Investigation of Mineral Soils; D. The Investigation of Peat and Muck Soils; and E. The Investigation of Forest Soils.

Under topic A, the authors discuss methods of sampling different types of soils. The use of the samples for profile studies, for mapping, and for research on the physical and chemical properties of soils is indicated. In Section B, the principal subjects dealt with are the mechanical analysis of soils, the determination of specific gravity, the determination of the heat of wetting, the determination of vapor absorption, the measurement of soil structure, the determination of the "critical" water relations, air content, and specific porosity. Section C supplies information on the analysis of soils by gravimetric and colorimetric methods. It has to do, likewise, with the ascertaining of the fertilizer requirements of soils and their microbiological investigation. Section D has

to do with the chemical and microbiological investigation of peat and muck soils. Section E deals in particular with the chemical study of various soils. The authors have presented the subject matter in a compact way and have made available to the teacher and research worker valuable reference material.

Electrokinetic phenomena and their application to biology and medicine. By HAROLD A. ABRAMSON, The Chemical Catalog Company, Inc., New York, 1934. Pp. 331, figs. 106, tables 57.

This book is one of the American Chemical Society series of scientific and technical monographs. Its relation to the other books in the series is indicated by the following statement of the editor of the series: "By arrangement with the Interallied Conference of Pure and Applied Chemistry, which met in London and Brussels in July, 1919, the American Chemical Society was to undertake the production and publication of Scientific and Technologic Monographs on chemical subjects. At the same time it was agreed that the National Research Council, in coöperation with the American Chemical Society and the American Physical Society, should undertake the production and publication of Critical Tables of Chemical and Physical Constants. The American Chemical Society and the National Research Council mutually agreed to care for these two fields of chemical development." The purpose of the editors is further indicated by the statement: "Two rather distinct purposes are to be served by these monographs. The first purpose, whose fulfilment will probably render to chemists in general the most important service, is to present the knowledge available upon the chosen topic in a readable form, intelligible to those whose activities may be along a wholly different line. Many chemists fail to realize how closely their investigations may be connected with other work which on the surface appears far afield from their own. These monographs will enable such men to form closer contact with the work of chemists in other lines of research. The second purpose is to promote research in the branch of science covered by the monograph, by furnishing a well digested survey of the progress already made in that field and by pointing out directions in which investigation needs to be extended."

The author, in his preface, says: "This monograph may find its justification in the attempt to bring together in a more or less harmonious whole, ideas and experiments from remote aspects of physics, chemistry and biology, many of them seemingly unrelated and obscure."

The scope of the monograph is indicated in the titles of the several chapters. They are: Historical; Early Theory and Related Experiments; Methods; Recent Theory and Related Experiments; Proteins and Some Related Compounds; General Effects of Salts on "Inert" Surfaces; Inorganic Surfaces; Organic Surfaces: Gases: Blood Cells, Spermatozoa, Tissues, Etc.; Bacteria, Antibodies, Viruses and Related Systems. There are three appendixes, dealing, respectively, with Notation, Constants and Conversion Factors, and Patent Literature. These are followed by author and subject-matter indexes. The

field of inquiry covered by this monograph is so broad as to make the book of wide interest to research workers in practically every important field. They have been placed under obligation both to the Board of Editors and the author.

Soil Analysis. A Handbook of Physical and Chemical Methods. By C. HAROLD WRIGHT. Thomas Murby & Co., London, 1934. Pp. viii + 236, figs. 6.

The methods of soil analysis developed within recent years have made obsolete many of the older analytical data. A vast mass of work was done with the hydrochloric acid extraction method. Much of this is now valueless. This fact has served to stress the importance of agreement among chemists as to methods employed in soil analytical work. Otherwise, the data obtained by different analysts are not comparable. The author of *Soil Analysis* has brought together the more recent as well as the older information on the technique of soil analytical work. For this reason, the book should be useful to many workers in the field of soil science. The author notes, in the Preface, that "While those engaged in the many branches of applied chemistry can obtain full details of their methods of analysis from laboratory manuals, the pedologist is to a large extent dependent on journals and other publications for the details of the methods of examining the soil." The author says, further: "Great care has been taken to include all the working details of each method. Under each heading is given a description of the method as it was originally described in the publication referred to; any additional information and comments by me are included in foot-notes. Data required in calculating the results are given for easy reference."

The book is made up of three parts, designated, respectively: Physical Methods, General Chemical Methods, and Special Chemical Methods. The appendixes deal with International Atomic Weights, Gravimetric Factors and Their Logarithms, Strengths and Equivalent Values of Standard Solutions. There are also author and subject-matter indexes.

The American Farmer and the Export Market. By AUSTIN A. DOWELL and OSCAR B. JESNESS. The University of Minnesota Press, Minneapolis, Minn. 1934. Pp. vi + 269, figs. 4, tables 15, illus. 2.

The export of agricultural products assumed importance even in our colonial times. The volume of exports gradually increased until we have come to depend on foreign markets for the absorption of large volumes of our agricultural commodities. Cotton and tobacco are notable among the crops depending on foreign markets for an outlet. Very substantial amounts of wheat and wheat products, corn and corn products, and pork and pork products have also played a prominent rôle among our agricultural exports. At the present time, there is much difference of opinion among economists as to the road which we are to follow in planning our agricultural production, particularly from the point of view of the absorption of our crop surpluses by the export markets.

The American Farmer and the Export Market represents a timely and intelligent discussion of a subject important to American agriculture and to the Nation at large. The authors have divided the discussion under the following topics: The Farm Plant, The Home Market, and The Export Market. The following may be quoted from the Introduction: "The depression has also stimulated a vast growth in economic nationalism. One of the ways by which this and other countries have sought to improve the situation of their agriculture and other industries has been through restrictions upon international trade. These measures force us to examine critically what export markets mean to the American farmer and what effect nationalistic policies have upon these outlets."

The book should be found helpful and useful in the classroom and to the student of economics. It should also furnish much food for thought to every intelligent reader. The facts marshalled by the authors are presented clearly and effectively. A considerable amount of tabular matter and a list of references add much to the value of the book.

Reshaping Agriculture. By O. W. WILLCOX. W. W. Norton & Co., Inc., New York, 1934. Pp. 157, figs. 10, tables 8.

More than ordinary interest may be attached to *Reshaping Agriculture* because of the rather fundamental changes that the agriculture of this and of other countries is now facing. The most available areas of free and virgin soils have been occupied. Much of the virgin fertility of the land devoted to the production of wheat, corn, rice, cotton, and other staple crops has been depleted. Erosion, cropping, and overgrazing have taken their toll. Students of soil science, as well as economists and statesmen, are now analyzing the problem of land use and are giving consideration to production levels as a significant factor in the maintenance of economic stability. The author of *Reshaping Agriculture* has presented in a most interesting way the possibilities that lie in intensified production and the limits which may be set to yields per acre. To quote the author: "Agricultural technology may never reach, in all its parts, the full condition of perfection foreseen for it by the agrobiologists: but in so far as it tends in any part to approach the limits set for it by Nature it may exert powerful effects on the political, social and economic stages; some of the effects of agrobiological developments are now very painfully evident. The intelligent citizen, not to mention the professional politico-economists and the social-economists who expect to have a share in planning a new social order (which appears to be overdue) must adjust his standpoint to the potentialities of plant life as these have been revealed by the agrobiologists."

The book is made up of a Foreword by Dr. Alvin Johnson, and of eight chapters, entitled: The Real Technical Basis of Farming; The General Relation between Input and Output in Farming; The Maximum Productivity of Land; The Demonstrable Yielding Power of Crop Plants; The Rising Technical Result of Farming; Abolishing the Weather Hazard in Farming; Social Intervention in Agriculture: and "Implementing the Era of Abundance.

Practical Everyday Chemistry. By H. BENNETT. The Chemical Publishing Company, New York, 1934. Pp. xv + 305.

It is evidently the author's intention to help the man in the street to find a better understanding of chemistry as it touches everyday life. To use his own words: "All your life you may have yearned to dabble and putter with chemicals. Perhaps you have been held back by lack of time, facilities, and knowledge. Shorter working hours have given many a leisure which can well be turned to 'riding' a hobby. What more fascinating hobby is there than chemistry? Chemistry—mysterious, alluring and everchanging. To make it even more interesting, why not apply yourself to the practical chemistry of the many things which you use or see daily. As for a laboratory, the attic, kitchen, basement or garage will answer."

The Introduction to the book consists of an explanation of weights and measures, and the main book consists of nineteen chapters. Chapter I, entitled "Abrasives," consists of a description of cements, glues, lutes, and pastes. The second chapter, "Agriculture and Garden Specialties," deals with animal remedies, fertilizers, insecticides, and weed-killers. The third chapter, entitled "Coatings, Protective and Decorative," has to do with lacquers, paints, varnishes, and stains. In the fourth chapter, "Cosmetics and Drugs," we find a discussion of antiseptics, bleaches, creams, deodorants, disinfectants, hair preparations, lipsticks, lotions, perfumes, pharmaceuticals, powders, and proprietaries. The reader will find similar treatment in the following chapters entitled: "Emulsions"; "Food Products; Beverages and Flavors"; "Inks, Carbon Paper, Crayons, Including Duplicators, Mimeograph and Typewriter Supplies"; "Leathers, Skins, Furs, Etc."; "Lubricants, Oils, Etc."; "Materials of Construction"; "Paper"; "Photography"; "Plating"; "Polishes, Abrasives, Etc."; "Rubber, Plastics, Waxes, Etc."; "Soaps and Cleaners"; "Textiles and Fibers"; "Miscellaneous"; and "Tables." The latter contains a list of trade names and suppliers. There is also a satisfactory index.

Practical Bacteriology. By ANDREW CUNNINGHAM. Oliver and Boyd, Edinburgh and London, 1934. Pp. viii + 203, figs. 26.

This a revised and enlarged second edition of the book. It is offered as a text for students in agriculture. The scope of the work is indicated by the titles of the seven chapters. The first three chapters deal with general bacteriological technique, including the preparation of culture media, the use of the microscope, the staining and microscopic examination of bacteria, and the cultivation and characterization of bacteria, moulds, yeasts, and actinomycetes. The following four chapters deal with bacteriology of milk, dairy products and water supplies, bacteriology of soil and farmyard manure, bacteriology of plant diseases, and bacteriology of animal diseases. The three appendixes contain matter relating to bacteriological tests for graded milk; stains and staining reagents; and indicators, chemical reagents, etc.

Practical Bacteriology will be found useful as a laboratory manual for students

specializing in soils, dairy and animal husbandry, plant pathology, and plant physiology. The author has outlined the subject clearly and has arranged the contents of the book in a manner to be most helpful to laboratory classes in introductory bacteriology.

JACOB G. LIPMAN.